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THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at 61 New Cavendish Street, London, W.1, on 1 January 1958, the Chair being taken by W. S. Ault, a member of Council.

The minutes of the previous meeting were confirmed and signed as a correct record. The names of members elected since the previous meeting were announced.

The Chairman introduced the authors, and the following paper was presented in summary.

LUBRICATION PROBLEMS ARISING FROM RAILWAY TRACTION MODERNIZATION *

By G. A. DICKINS † and W. B. BROADBENT †

SUMMARY

A review of railway traction modernization indicates no entirely new lubrication problem, but that existing operational experience on differing power components can be specifically applied to this programme. Dieselization, with its requirements for satisfactory crankcase lubricant, appears to be an interim stage in a final translation to electric traction, and this can cause economic problems for the oil industry. The lubrication problems of diesel traction are reviewed under the three categories of diesel shunters, railcars, and main line locomotives, only the latter being essentially new to the U.K. Types of lubricant are considered against the background of the duties involved and other relevant factors, such as fuels and mean brake effective pressures. The need for good co-operation between the railways and oil companies is stressed, especially in the establishment of a satisfactory lubrication service capable of ensuring good life through proper maintenance. Suggestions for analysis procedures on diesel crankcase oils are made, together with some general observations on interpretation of test data and the difficulties associated with the reclaiming of oils. Transmissions and their related problems are reviewed. Grease technology is developing to meet the increasing requirements of railway traction for lubrication of heavily loaded and high speed anti-friction bearings. Some possible future developments in the use of dual fuels and free piston engines are outlined.

INTRODUCTION

THE modernization of railway equipment does not introduce many entirely new problems to the oil industry, but it does introduce new techniques in railway operation which require the closest liaison between the two industries in order that the maximum benefits may be enjoyed from the large capital outlay envisaged.

To achieve this object it is desirable to appreciate first a little of the traditional background of the railway industry and also just what is the true perspective of present modernization trends as related to traction.

In assessing the influence of lubrication during the early days of locomotion let us compare two dates; in 1803 Trevithick built his first locomotive at Pendarron, whereas it was not until 1854 that Professor B. Silliman's analysis of a sample of petroleum indicated the importance of its lubricating properties. Thus, during the first half-century of the locomotive's history, development was limited by the necessity to use vegetable and animal oils, which were quite unsuitable for the requirements involved. In the following half-century, refinements in mechanical efficiency and reliability were largely a function of the advances made in lubricants and their application.

The modern era of traction equipment development has the advantage that experience in the operation of the various power components has been largely gained in other fields; therefore the problem of lubrication is frequently a matter of the application of this experience to the special requirements involved, together with adequate control and training to school staff in the correct interpretation and resultant maintenance needs.

The following figures quoted from British Railways modernization plan illustrates the true balance of development during the next decade and a half, shared by the different methods of traction in the U.K.:

Capital expenditure on coaching stock	£230,000,000
Capital expenditure on electrification	£210,000,000
Capital expenditure on freight stock	£177,000,000
Capital expenditure on diesel locos	£150,000,000

It must also be accepted that, with the exception of shunting units, diesel locomotives, as opposed to railcars and rail buses, are likely to be little more than the interim stage between steam and electric operated main lines, particularly in view of the nuclear power programme. This presents a long-term economic problem to the oil industry of probably equal consequence to any of the technical problems which are immediately with us as the result of diesel traction. Incidentally, this aspect presents an even greater production problem to the locomotive manufacturers, but is one of which this industry is clearly well aware, as evidence of mergers between many large locomotive

* MS received 1 October 1957.

† Mobil Oil Co. Ltd.

and electrical equipment manufacturing combines in recent years have shown, a process which was in the first place happily wedded by the construction of diesel-electric locomotives.

The lubrication problems arising from electrification are not great, since there is a background of experience of electric traction in the U.K., although some new problems have arisen due to the new type of system now being introduced. However, main line diesel traction on a large scale is new to the U.K., although manufacturers have for some time been producing diesel units for the export market, and it is in this particular field that service life between overhauls is so dependent on the quality of the crankcase lubricating oil; other factors, such as operating condition and design, obviously warrant every consideration.

Diesel traction can be subdivided into three categories, namely, diesel shunters, railcars, and main line locomotives, and in each of these categories differing lubrication requirements arise.

Details are provided showing the types of unit in these categories, and the probable lubrication requirements of diesel engines and transmissions to be employed. In addition, the differing types of electric traction and their lubrication needs are also discussed.

There is already very comprehensive diesel locomotive experience available in America, and also, to a lesser extent, on the Continent, but knowledge of the diverse lubrication requirements connected with railway traction is still being assimilated as development proceeds both in the laboratory and in the field, and experience continues to be gained which is of value to both the user and the supplier of lubricants.

THE DIESEL ENGINE

There are two fundamental limitations on the design of traction diesel engines, those of space and weight. There is, however, an overall essential in achieving a successful unit for rail transportation, and that is reliability, which is more important perhaps than specific output and fuel consumption; hence it is essential that the diesel locomotive should compare favourably in this respect.

It is not always easy to ally reliability with the imposed limitations, and in fact there have been a number of examples of satisfactory stationary engine designs being up-rated to give a good traction power/weight ratio with resultant reduction in reliability. The present trend, largely made possible by improved designs, is to rate the traction diesel engine conservatively.

However, supercharging of large engines and the high speed and consequent arduous combustion conditions of the small engines demand the use of superior lubricants to combat deposits and wear. This applies particularly when an engine is running at maximum rating, but with railway traction a surprisingly high proportion of operating time will be spent at low load and idle conditions; therefore, the low temperature characteristics (*i.e.* sludging potentiality) of the lubricant must be taken into full account.

In the U.K. this low load operation is acknowledged by placing main line diesel locomotives into the following classifications:

	H.p.	Maximum speed, m.p.h.	Axle load
Type A	600–1000	60	17 tons, up to 800 h.p.
Type A	600–1000	60	18 tons, 800–1000 h.p.
Type B	1000–1250	75	18¼ tons
Type C	2000 and over	90	20 tons

Correct allocation of locomotive to duty requirement by the operating staff will obviously reduce the low load factor.

The lubrication of traction diesel engines may be considered, perhaps, in these groups:

Group I	600–800 rev/min developing up to 400 h.p.	Mostly shunting locos
Group II	600–1200 rev/min developing from 800–2000 h.p.	Main line and mixed traffic locos
Group III	1500–2000 rev/min developing up to 250 h.p.	Railcar and light weight trains

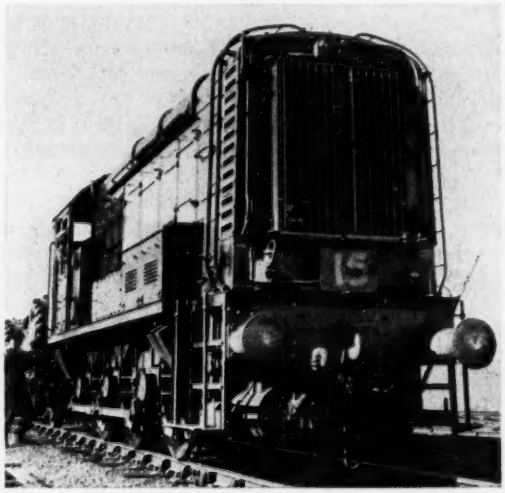

FIG 1

BRITISH RAILWAYS STANDARD 350-H.P. LOCOMOTIVE INCORPORATING ENGLISH ELECTRIC POWER EQUIPMENT AND TWO NOSE SUSPENDED TRACTION MOTORS

Obviously there are exceptions to these generalizations, but on the whole, traffic and design trends have resulted in this general pattern, which also effectively breaks down all types of diesel into three main categories, *i.e.* shunter, railcar, and main line.

For the purpose of this paper the relative performance of crankcase oils, in so far as their ability to prevent deposits and wear (*i.e.* detergency) and bearing corrosion are concerned, is referred to in terms of Regular Grade, which should include an anti-oxidant, 2-104-B, MIL-L-2104-A, or DEF/2101-A, Supplement I, Series II, and Series III oils. It is not proposed to discuss these differing levels of oil performance, since much has been published on this subject in recent years; [1,2] but it should perhaps be stated that most oil companies having research, development, and technical service laboratories at their disposal have engine testing facilities available, so that oils can be developed to meet any of the performance levels mentioned above which are found necessary for particular diesel rail traction units.

Clearly the type of lubricant required is dependent on the cylinder combustion conditions; this can to a large extent be related to the brake mean effective pressure, which, on the conservatively rated, moderate power/weight ratio shunter engines, will be in the region of 85 lb/sq. in., whereas the supercharged high horse-power main line units are being designed to give their outputs with b.m.e.p. around 165 lb/sq. in.

It is not going to be an economical practice to employ one grade of lubricant throughout with such a wide divergence of cylinder outputs, and it is the authors' opinion that with an organization which is so conversant in the discriminate handling of lubricants as the railways have traditionally been, there is little justification for over simplification of stocking.

In Group I, which includes the majority of shunting locomotives (Fig 1), it is found most engines have b.m.e.p. of under 90 lb/sq. in., and experience has shown that a good solvent refined regular grade oil, generally SAE 30, blended with an anti-oxidant, is entirely satisfactory.

In Group II, which includes mixed traffic and main line locomotives and also American " switchers," are found the higher b.m.e.p. supercharged engines (Fig 2), and these in general call for detergent oils to the MIL-L-2104-A or DEF/2101 level—generally SAE 40 for U.S.A. locomotives, and SAE 30 for European designs.

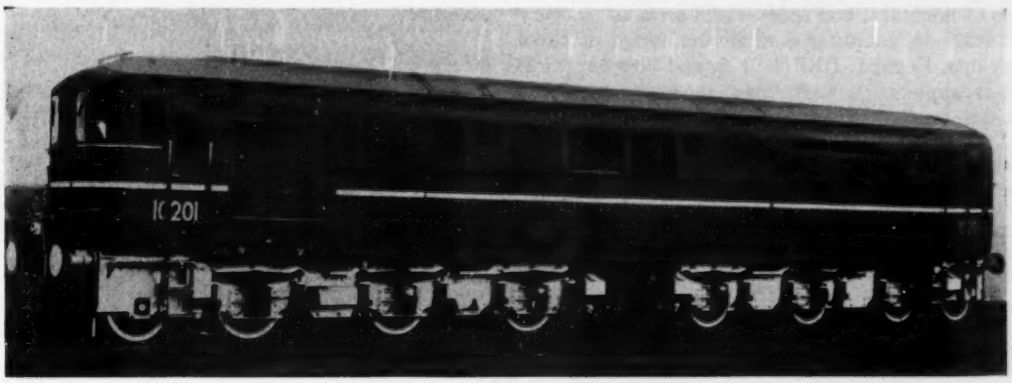

Fig 2

BRITISH RAILWAYS 1750-H.P. MAIN LINE LOCOMOTIVE INCORPORATING ENGLISH ELECTRIC POWER EQUIPMENT

Leading undriven wheels on each bogie reduce axle loadings to allow maximum route availability.

Group III includes the majority of the small high speed engines for railcars and rail bus use (Fig 3). These are often commercial vehicle-bred designs, hence there is a preference for a high viscosity index oil which gives easier starting with allied consumption improvement and greater oxidation stability. Again, a detergent oil is required for this service, and practice tends to support that both maintenance and lubrication economies can be obtained by the use of a Supplement

Fig 3

BRITISH RAILWAYS STANDARD RAILCAR UNIT CONSISTING OF ONE POWER CAR AND ONE TRAILER CAR

Each power car has two 150-h.p. horizontal underfloor mounted engines, and the twin sets may be coupled and controlled in multiple.

I type oil. The relative prices of fuel and lubricant generally result in the adoption of an SAE 30 grade of oil.

Variations in engine selectivity in each of the arbitrary classifications aforementioned can usually be met by the use of one or other of these three general types of lubricant, and there would seem to be every advantage in adopting a minimum range of three lubricants, Regular, DEF/2101-A, and Supplement I.

It is appreciated that fuels can have a marked influence on the performance and reliability of diesel engines, and that their influence cannot be entirely divorced from the lubrication requirements; *e.g.* high sulphur and ash contents can adversely affect both deposits and wear; also insufficient volatility, as characterized by a high distillation point curve, can cause poor fuel atomization and inadequate mixing with air, resulting in inefficient combustion, hence again promoting deposits and wear. Inadequate cetane number may result in difficulty in starting or intermittent combustion under light load, which in turn would increase deposits and wear.

Since the quality of a diesel crankcase lubricant can also significantly influence deposits and wear, it follows that the selection of a lubricant should not be made without reference to the type of fuel used. In the case of railway traction, however, it is not anticipated that residual containing fuels will be used such as are covered by B.S.S. 209-1947, Class B specification. The type of fuel most likely to be used, both in the U.K. and abroad, will probably be covered by Class A of this specification.

There is at present little trouble from fuels in British Railways, where a limitation of 1 per cent sulphur on the Class A specification has been adopted. It is known that most systems in the U.S.A. stipulate a maximum sulphur of 0·7 or 0·8 per cent, therefore there is no wide divergence of opinion on this feature.

Considering the three main categories, shunters, railcars, and main line locos, in the light of experience so far gained the following illustrations will perhaps indicate the aspects of dissimilarity between each category:

(1) *Shunters*

Many units operating to-day incorporate the English Electric Company's six-cylinder naturally aspirated 400 b.h.p. engine. The b.m.e.p. at this rating is 82 lb/sq. in. For this engine it was decided to employ a regular grade oil, and a lubricating oil analysis procedure was set up on ten locomotives to determine service life. A specimen of the analysis results obtained as being typical is given in Table I.

It will be noted that over a period of 2½ years there was not sufficient build-up of insolubles to require a benzene figure. The oil continued in service until

TABLE I

Engine No.: 12119					Date into traffic: 9 September 1952		
Date drawn	15.7.53	13.10.53	8.1.54	14.6.54	13.7.54	12.12.54	14.4.55
Sample no.	G.1	G.2	G.3	G.4	G.5	G.6	G.7
Mileage, total	3772	5394	6177	7727	10,007	16,321	19,488
Specific gravity at 60° F	0·923	0·922	0·922	0·920	0·921	0·920	0·918
Flash point, open, ° F	410	415	405	—	410	395	405
Viscosity at 100° F:							
Centistokes	138	138·6	125·7	145·8	139	139	136
Saybolt	636·6	642	582	676	644	644	630
Redwood	559	564	511	593	565	565	553
Colour	Dark	Dark	Dark	Dark	Dark	Dark	Black
Fuel, %	<2	Trace	<2	1	1 approx.	1	1 approx.
Insolubles in pentane, %	0·03	0·05	0·05	0·05	0·10	0·35	0·10
Water in oil	Trace	Nil	Nil	Trace	Trace	Nil	Nil
Free water	Nil	Nil	Nil	Trace	Nil	Nil	Nil
Impurities	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Ash, %	Trace	0·06	Trace	0·01	0·007	0·02	0·04
Major constituents	Trace iron	Iron	Iron	Iron, etc.	Iron, calcium, silicon	Phosphorus	Phosphorus, iron, silicon
Minor constituents	—	—	—	Tin	Phosphorus	Silicon	Zinc, tin

TABLE II

Engine number	Average liner wear (inches)
12113	0·0014
12114	0·0017
12115	0·0014
12116	0·0021
12117	0·0021
12118	0·0025
12119	0·0024
12120	0·0026
12121	0·0026
12122	0·0017

the locomotive went to works for intermediate overhaul.

A further table (II) is given showing the average cylinder liner wear of the ten locomotives at the conclusion of the analysis survey.

TABLE III

Engine No.: 13162 — Date into service: 16 September 1955; Date filled with detergent oil: 4 April 1956

Date drawn	7.8.56	25.10.56	21.1.57	5.5.57
Sample no.	1	2	3	4
Flash point, open, ° F	420	430	430	395
Viscosity at 100° F, cS	115	119	119	115
Colour	Black	Black	Black	Black
Fuel, %	2 approx.	2 approx.	2 approx.	2 approx.
Insolubles in benzene	0·65	0·60	1·30	1·25
Insolubles in pentane	0·65	0·65	1·50	1·30
Water in oil	Slight trace	Trace	Trace	Trace
Free water	Nil	Nil	Nil	Nil
Ash, %	0·67	0·64	0·71	0·65
Major constituents	Barium, calcium	Barium	Barium, aluminium	
Minor constituents	Aluminium, phosphorus, iron	Phosphorus, calcium, aluminium, zinc, silicon	Phosphorus, calcium, magnesium, tin, iron	

Locomotive No. 12114 underwent a repair during August 1957 at which the liner wear was again taken and a maximum of 0·004 inches recorded. This is stated to be typical, and the report on the pistons states "Very little carbon—generally clean; no lacquering and all rings free." Oil changes can be confined to periods of shop repair with these engines.

A similar power class of shunter is now coming into service in increasing numbers, and a survey similar to the one referred to above is being undertaken. The survey has not yet run its span, but initial results provide an interesting comparison. The engine is the Blackstone type ER6T, and in the first place was lubricated with a non-detergent oil (Fig 4). Early results confirmed the builder's recommendation that a detergent oil should be used, and an example of readings obtained so far utilizing a MIL-L-2104-A detergent oil is given in Table III.

No wear figures are yet available from this class of engine, but it will be noted that an appreciable quantity of insolubles has built up during the year reviewed, which is typical of these engines, having a B.M.E.P. of 86 lb/sq. in.

(2) *Railcars*

The majority of railcars in service in the U.K. have a modified road vehicle engine with a horizontal mounting favoured. On the Continent a much greater diversity of engines has been adopted with much emphasis on bogie-mounted designs rather than the underfloor mounting which is without exception in the U.K.

FIG 4

DIESEL-ELECTRIC 350-h.p. BLACKSTONE/G.E.C. POWER UNIT

Typical readings obtained with 11·3-litre B.U.T. engines are given in Table IV below, wherein it is possible to compare results obtained with a DEF/2101 detergent oil and a Supplement I type, at the same time illustrating the greater mileage which is possible when using the oil with greater detergency, which latter oil can hold a greater quantity of insolubles in suspension.

TABLE IV

	Car No. 79098 (using DEF/2101-A detergent oil)						Car No. 79020 (using Supplement I oil)					
	Engine No. 1			Engine No. 2			Engine No. 1			Engine No. 2		
Sample no.	1	2	3	1	2	3	1	2	3	1	2	3
Mileage since oil change	2650	3370	5540	2650	3370	5540	5390	7090	9050	5390	7090	9050
Viscosity at 100° F, cS	113	112	116	112	112	115	—	—	—	—	—	—
Fuel, %	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Flash point, open, ° F	420	420	430	440	435	430	405	420	425	415	435	430
Water in oil	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Water, free	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Insols in pentane, %	0·65	0·70	1·20	0·75	0·75	1·55	1·35	1·30	1·20	1·30	1·50	1·45
Insols in benzene, %	0·60	0·60	1·10	0·65	0·65	1·45	1·25	1·30	1·15	1·25	1·45	1·35
Colour/appearance	Black	Black	Black	Black	Black	Black	—	—	—	—	—	—
Ash, %	0·56	0·59	0·60	0·55	0·58	0·60	1·04	0·99	1·04	1·01	1·02	1·03

Car No. 79098, and others in the same district, are now operating 12,000 miles between oil change and engine condition remains satisfactory. The other cars, using the DEF/2101 level, are having oil changed at 6000 miles. Similar make-up oil is required at a rate of approximately 1 pint/175 miles, and it has been possible to calculate from practical results that an appreciable saving on lubrication costs results from using the higher detergency oil, apart from the potential maintenance savings.

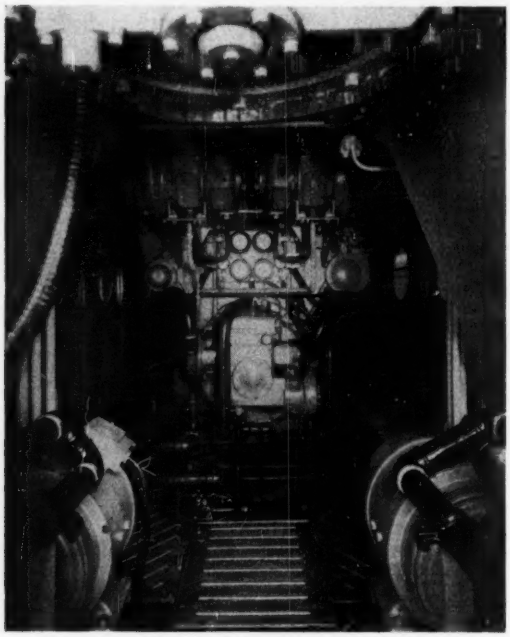

FIG 5

END VIEW OF ENGLISH ELECTRIC 16 SVT PRESSURE CHARGED DIESEL ENGINE AS MOUNTED IN A 1600-H.P. LOCOMOTIVE

(3) *Main Line Locomotives*

It is in this field that U.K. experience is largely lacking, although several conventional prototype locomotives of between 1600 and 2000 h.p. have been running since 1948.

The many traction diesel engines in the U.S.A., which it should be added are all designed and built by a relatively small number of suppliers who have specialized in this field, are mostly in this horsepower range and run most economically on MIL-L-2104-A type detergent oils.

Experience in the U.K. with a supercharged V-16 engine (Fig 5) forms the source of Table V. Oil change, during five years of analytical service, was determined throughout by laboratory results. When the engine was newly overhauled 1500 hours could be expected between oil change; as a major overhaul period was approached this might be reduced to 750 hours, which supports the desirability of controlling oil change on main line locomotives by oil condition rather than on a mileage or periodical basis.

It is interesting to note that the maximum oil life in the U.K. on these larger units is approximately that of the minimum period for similar units in the U.S.A. This is thought to be a function of the different load demands on engines nominally performing comparable duties.

LUBRICATION SERVICE

Having selected the lubricant, there is then the all-important question of determination and control of quality. This is not new to oil companies, but the technique of sampling, analysis, and, above all, interpretation is fresh ground for railway personnel.

In the first instance it must be accepted that large-scale dieselization necessitates an adequate

TABLE V

Analytical Data on Engine No. 10001 (*using DEF/2101-A oil*)

Type of work: *passenger*							
Total miles from overhaul	3140	5270	6800	14,200	20,200	26,800	32,000
Miles from oil change	3140	5270	6800	14,200	20,200	26,800	32,000
Viscosity, Redwood, at 140° F, sec	162	166	168	169	167·2	173·8	184·5
Specific gravity	0·908	0·906	0·909	0·909	0·911	0·918	0·922
Insolubles in petroleum ether, %	0·66	0·34	0·61	0·87	1·0	0·65	1·55
Insolubles in chloroform, %	—	—	—	0·42	0·8	0·2	1·35
Flash point, open, ° F	440	430	440	435	430	435	435
Type of work: *freight*							
Total miles since overhaul	92,330	94,130	95,530	96,830	} Locomotive called in for general overhaul		
Miles from oil change	1500	3300	4700	6000			
Viscosity, Redwood, at 140° F, sec	172	164·3	181·2	174·3			
Specific gravity	—	—	—	—			
Insolubles in petroleum ether, %	0·45	0·64	1·15	1·43			
Insolubles in chloroform, %	—	0·52	0·72	0·5			
Flash point, open, ° F	416	410	378	380			

analytical organization. This can be approached in two ways:

(1) Frequent quick determination of the essential characteristics by local railway maintenance staff, followed up by more comprehensive periodic main laboratory analysis.

(2) Comprehensive analysis progressed so speedily that results can be made available to the relevant depot to safeguard engine condition effectively.

Both services should always include the provision of a technologist who can converse on equal terms with the user or manufacturer. He should be able to assess the engineering and lubrication problems involved and assist in determining maintenance schedules; he should also arrange lubricant sampling procedures.

The technologist should also be backed by adequate laboratory facilities so that a detailed analysis can be carried out on all lubricant samples submitted. Such analysis should enable an assessment to be made as to the working life of the lubricant, and perhaps the condition of the unit lubricated. Any analysis should, of course, be assessed initially in conjunction with maintenance details on the cleanliness and wear of the units concerned, taking into account operating conditions, and a comprehensive report issued to the user on the findings.

As experience is gained with one particular type of operation on a given lubricant, so it should be possible to establish what features of the analysis are critical in respect of the necessity to use a new charge of lubricant or perhaps to examine or overhaul the unit concerned. However, it should not be assumed that it is always possible to determine maintenance periods from oil analysis alone.

TABLE VI

Lubricant Service Analysis, Suggested Tests and Information

Type and engine no. of unit
Sample no. and date
Total mileage
Mileage since last oil change

Specific gravity at 60° F
Viscosity at 100° F, S.U.V., cS., Redwood No. 1
Fuel dilution
Flash point, open, ° F
Water in oil
Water, free
Insolubles in pentane, %
Insolubles in benzene, %
Colour/appearance
Ash, %
Major constituents of ash
Minor constituents of ash
Trace constituents of ash
Neutralization value, mg KOH/g.
TBN or NSAN

Table VI provides details of the type of comprehensive analysis that is suggested as a regular service for railway traction operations, and the appendix gives details of a method of interpretation of such an analysis.

To operate entirely on laboratory analysis the railway system must be compact, and the laboratory highly accessible to all depots employing diesels. This system has been applied with success on certain railways on the Continent and in the U.S.A., the using depot receiving a 48-hour service, and oil change being entirely under the control of the laboratory personnel. This is a tidy method of dealing with the problem, but even considering British Railways on a regional basis, it is not easy to contemplate their successful application of this system. It is perhaps not always appreciated that the route mileage of British Railways is greater than that of any one of the American railroads, and twice that of all but four of these heavily dieselized systems.

The adoption of field testing of the essential oil characteristics has many advantages to the operator with widely dispersed depots and can, with experience, eliminate a great deal of expensive central laboratory work. To implement such a system will require suitable accommodation at any depot where installation is justified for the limited laboratory equipment needed, the training of staff in the competent handling of the equipment, and an efficient system of sampling and reporting results. Each administration will decide what tests should be conducted by this means, but it is suggested that as any analysis is primarily seeking the unexpected as an insurance against possible damage, and secondly, the confirmation of expected trends, it is thought that field analyses can be quite brief, consisting of a viscosity check to determine either excessive reduction or increase, and a flash point determination as an approximate measure of fuel contamination.

Blotter or "spot tests" can be useful, dependent upon several factors. The most important would appear to be the frequency of inspection of the units and, again, the experience of the operators. Where periodic inspections are made, the results of spot tests can show significant trends, although testing such as this should be regarded as subsidiary to properly staged analyses under controlled laboratory conditions.

As an illustration of how easy it could be to allow somewhat empirical figures to dominate practice, the following (Table VII) is of interest.

TABLE VII

Field Service Tests of Railroad Diesels
(1 per cent Sulphur Fuel)

Locomotive	Service	New Oil Properties			Average oil miles to reach pH 4	Average oil change period miles
		pH	T.A.N.	T.B.N.		
A	Switching	9·4	0·19	1·34	1600 hr	7000 hr
B	High speed	8·2	1·05	0·73	56,000	100,000
C	Heavy freight	8·2	1·38	0·57	8000	35,000
D	Medium duty freight	7·9	1·07	1·41	8000	60,000
E	Heavy freight	10·6	0·44	2·32	11,000	30,000

A reading of a number of U.S.A. reports on the subject of alkalinity in used detergent oils, a somewhat controversial subject, indicated that, whilst a lower condemning limit of pH is not defined, a logical assumption could be a value of 4. Table VII shows that none of the oils in the five locomotives were changed at the mileage (or hours in one instance) at which pH 4 was reached, but all engines were satisfactorily lubricated without sacrificing their availability for their assigned purposes. It is possible that even better engine conditions would have resulted if the oils had been changed at a pH of 4, but it would not have been practical to do so.

Laboratory engine detergency tests have been run on used detergent oils from service locomotives in an attempt to correlate used oil properties with remaining detergency effectiveness measured by engine cleanliness, and results showed that, in general, detergency and alkalinity decreased with increased locomotive service time. However, several samples with strong acid numbers (pH below 4) still rated high in detergent effectiveness, and this indicates that factors other than arbitrary pH values must be used in determining oil drain periods for lubricating oils.[3]

Field testing service should be followed by a periodical comprehensive analysis, and special mention should be made of the use of an emission spectrograph, since this is a relatively new instrument in the field of oil analysis.[4] Used crankcase oils contain minute amounts of certain metals indicative of normal wear in addition to any metals present from metallic additives. By testing regular oil samples the emission spectrograph can trace increases in the concentrations of any metals caused by abnormal wear conditions within the engine, so that the need for engine inspection is revealed long before the failure of the component concerned; this is a valuable insurance against trouble.

The relating of these data to engine operation must be based on experience in determining significant deviations from normal metal concentrations present for a particular type of unit under a particular set of operating conditions. However, such observations cannot always provide a correct assessment of component malfunctioning.

Discussions on drainage periods inevitably lead up to the question of used crankcase oil disposal and to the advantages and disadvantages of reclaiming these oils. This is a lengthy subject in which much has been said, but the position may be summarized in this way. The oil companies have been cautious in recommending this procedure, not only because it presents practical operating and economic difficulties for themselves, if called upon to do this work, but principally through their desire to ensure good performance by supplying products to approved levels. In the railway modernization scheme the volumes of used oils involved suggest that the situation be re-examined.

First, the reclaiming of oils, if warranted, must be carried out in well-designed plant and under established conditions where other contamination can be avoided and in which steam stripping is used as an accessory to filtering; full re-spiking of the oil to the original level should then follow. It is true that, in the laboratory, only small differences can be detected between the original oil and the original oil blended with sizeable percentages of the reclaimed product. In view of this a sound recommendation would be to use reclaimed oil for topping up purposes in modest percentages, of the order of 10 per cent.

TRANSMISSIONS AND THEIR LUBRICATION REQUIREMENTS

The steam locomotive, apart from the occasional and usually unsuccessful attempt to the contrary, has a drive of the utmost simplicity, and also is able to exert full torque at zero rev/min. At the same time, practice has shown that for different classes of work, main line passenger, mixed traffic, and heavy freight, benefits are gained by variations in driving-wheel size so that a suitable cylinder horse-power may be developed at the normal track velocity of each type of duty, which involves completely different designs of main frames, wheel arrangements, and often cylinder layout.

The diesel engine can provide a useful torque only within a fairly narrow range of engine speeds; therefore, some form of transmission having a variable speed ratio must be employed so that the engine may run within its proper speed range irrespective of track velocity. Accepting that this additional equipment is essential, it does often mean, however, that a diesel-powered locomotive can be more ubiquitous in its service than an equivalently powered steam unit.

Ideally the horse-power at the rail should remain constant, giving a high tractive effort at low train speeds with a rapid falling off as speed increases, and this should be obtained with the diesel engine maintaining constant torque at the required driver's throttle setting.

There are three common forms of transmission used, each having its own advantages and adherents, and in some cases used in conjunction with one another, namely, electric, hydraulic, and mechanical.

The capabilities and limitations of these are hardly within the scope of this paper, but existing practice tends to favour electric transmission for the largest locomotives and mechanical transmission for the smallest. The present British Railways modernization scheme calls for a representative number of hydraulic drive units in the middle power class, which in certain cases are to be duplicated on one frame to form a locomotive in the top horse-power range.

The *electric transmission* necessitates a generator which is normally direct coupled to the diesel engine

crankshaft and therefore requires only one outboard bearing. This is generally an anti-friction grease-lubricated bearing requiring a high-temperature stable long life product which, by to-day's standards, is best met by a multi-purpose lithium grease. A similar lubrication requirement exists with the traction motor bearings, where there is a high temperature and somewhat critical bearing duty. The number of motorized wheels is largely dependent on the weight of the locomotive and permissible axle loadings. Commonly, for the larger locomotives, six-wheeled bogies are employed, and it is usually found convenient to power each axle, although certain medium-power locomotives have six-wheel bogies with the two outside axles powered and the centre axle acting as a weight-carrier only.

The final drive spur gears have a harsh duty to perform. Not only have they to transmit high unit teeth loadings, due to the restriction on space, but there are local speed surges and shock loads imposed by the inevitable undulations and breaks in the rail-head surface offered to the driving wheels.

Early electric passenger vehicles favoured grease for this application, but latterly an improvement in gear tooth life has been shown by the use of products which are sufficiently bituminous to ensure adhesion to metals, thus helping to overcome pitting due to intermittent over-stressing. The use of these viscous materials introduces very considerable frictional losses due to the lubricant's tenacity, and has also been the cause of wheel tread damage when motorized vehicles have been towed under cold ambient conditions, resulting in non-rotation of the geared wheels.

Modern mild E.P. additive gear oils can be employed quite successfully from the lubrication standpoint, but there is a further aggravating feature to contend with in that space limitations are such that it is difficult to design adequate seals between the pinion and gear case to exclude oil from the traction motor. A compromise may be found in the use of heavy viscosity mild E.P. gear oils, sufficiently viscous to resist flow past the seals, but yet still retaining the flow advantages of an oil. Early results in the use of such oils are promising.

The question of application is important where the use of viscous lubricants is involved, and traction gear manufacturers are not always sufficiently sympathetic in their approach to arranging the accessibility of the lubrication point.

Hydraulic transmissions really fall into two classes —one is essentially a fluid drive between engine and speed-change box in which the hydraulic fluid can normally be the same as the engine sump oil; the other incorporates all speed-change devices, leaving only the final drive, which may include the reversing gears, as an additional unit.

The hydraulic drive has received most favour in Germany, but is practically unused in America, where electric transmission is most popular. The Voith transmission system is widely applied, and since these transmissions have been marketed by a major U.K. locomotive builder, they may be found in many Commonwealth countries as well as Britain. This hydraulic turbo transmission has three fluid circuits; a torque converter for starting and low speeds, and two fluid couplings, one for medium and one for high-speed range. The torque converter and fluid couplings are self-contained, and are engaged by filling and disengaged by emptying.

Normally the diesel engine and transmission are separately mounted and connected with a flexible coupling. The torque converter and fluid couplings are engaged through an automatic governor which depends on the locomotive speed, and when the filling valve opens through the operation of the throttle, oil is fed by the pressure pump to the governor and thence to the converter. When the throttle is further opened, the engine speed and rail speed increase until the governor directs the oil to No. 1 coupling and empties the converter. As the rail speed continues to increase, the governor directs oil to No. 2 coupling and empties No. 1 coupling. The reverse takes place as speed falls.

It will be appreciated that the gear ratio between input and output shafts of the transmission is determined by the engagement of the converter and couplings, all trains of gears being in constant mesh. The same oil is used for the hydraulic medium as for gear lubrication, the former requiring extreme mobility to ensure rapid and smooth speed change, and the latter requiring a lubricant of sufficient film strength to deal with the high unit tooth loads imposed by the necessity of space conservation within the transmission. The provision of such a product for the higher horse-power transmissions (Fig 6) has required many years of research with the builders to achieve, in addition to the above required characteristics, the chemical and physical stability and resistance to foaming necessary to ensure reliable and efficient operation.

A transmission employing an interesting fluid coupling and four-speed constant mesh gear box arrangement has the primary drive put through a torque converter in which the turbine part can be moved axially, so allowing a second ring of blades to be brought into play giving a weak backward torque when a speed change is being made through the Karl Mayback over-running clutch. This unit is a neat combination of hydraulic/mechanical transmission, but the speed change is actually provided by selecting gears and not hydraulically, and the diesel engine oil is satisfactory for the converter.

Mechanical transmission—for shunting locomotives and railcars in the 100-h.p. range gear boxes are often employed having a gear change effected through cone clutches, which are probably hydraulically operated. For slightly higher horse-powers it is usual to find

constant mesh gears with some form of friction clutch for the selection of each, the clutches being power operated, and generally the arrangement consists of epicyclic gears with the clutches in the form of brake bands. Although it is usual to find a fluid coupling between engine and gear box, it is possible, through mismanagement of controls, for excessive heat to be generated by these clutches, which are, of course, working inside the gear box and amongst the gear oil. A high viscosity index SAE 20 oil, with rust and oxidation inhibitors, has been found most suitable for this type of gear box, and may remain in service unchanged for periods in excess of 60,000 miles.

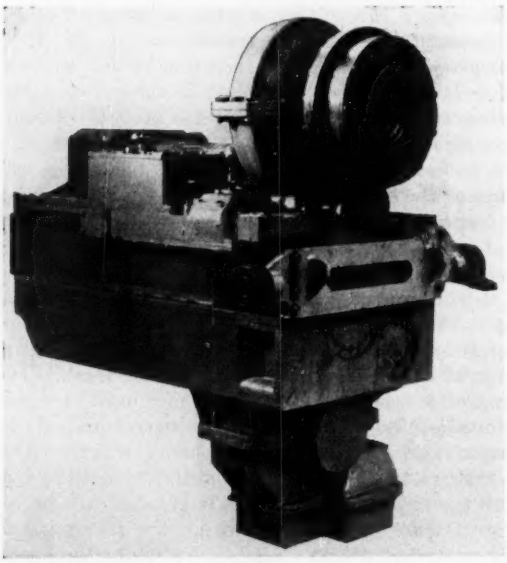

FIG 6

VOITH NORTH BRITISH FULLY AUTOMATIC HYDRAULIC TRANSMISSION TYPE L 306 R SHOWING MAXIMUM INPUT 1100 H.P. AND OUTPUT FLANGES

An interesting design which sets out to achieve the efficiency advantage of a mechanical drive in a high powered locomotive (2200 h.p.) is the "Fell" locomotive, in which four separate engines drive through fluid couplings and differentials to the main gear box, high torque at starting being provided by one engine driving through the gear reduction of the remaining "locked" differentials and track speed increases being made by progressively bringing the other engines into use. The power curve obtained by this method is excellent, but it has proved difficult to conveniently lay out the design of such a machine for maintenance.

ELECTRIC TRACTION

This is the long-term economic objective in the modernization of trunk routes with heavy line occupation. In many cases these routes will overlap with dense suburban services, and the prior existence of suburban electrification will, certainly in the case of one region of British Railways, influence the method of electrification.

Where electrification is carried out on new routes a high voltage overhead wire policy has been decided upon. The lubrication of mechanical parts follows closely the requirements of the electrical side of diesel-electric locomotives, but perhaps the problem of traction motor anti-friction bearing lubrication may be considered more fully under the above sub-heading.

The fact that a problem exists is primarily a matter of limited space and increasing power demands. Width limits imposed by gauge, power to be developed by motors and transmitted through traction gears, incur the use of as narrow anti-friction bearings as possible; therefore, the tendency in catering for increased loadings is to increase the bearing diameters.

At the same time increasing power outputs, together with the use of high voltage alternating current, dictate higher motor speeds than previously adopted, and it will be appreciated that all these factors combine towards greater churning of any lubricant in the bearings.

In considering this feature it is usual to use a dynamic factor which is related to diameter and rotational velocity. This may be expressed in one of two ways, either by multiplying the bore diameter of the inner race (d) by the revolutions per minute (this is referred to as the dn value), or by multiplying the mean diametral measurement of d and D, where D is the outside diameter of the outer race, by the rev/min, and this may be referred to as the d_mn value.

The d_mn expression gives the higher numerical values and for tapered or spherical roller bearings a mechanical arbitrary limit of 350,000–400,000 has been adopted. Cylindrical roller bearings have been permitted to run up to 600,000.

It is not possible to lubricate traction motor bearings with oil, whereas grease lubrication has been proved fully satisfactory in dealing with values up to 350,000 d_mn. Future traction design will bring in values up to 600,000 and given good bearing precision they can be grease lubricated satisfactorily. Already, accurate methods are employed to ensure the optimum quantity of grease being packed into these bearings, and it is suggested that the time has now come when facilities for replenishment in service will have to be provided, which will also necessitate an overflow arrangement and good maintenance procedures.

To a lesser extent the large-scale adoption of anti-friction bearings for the carrying axle journals of locomotives and future rolling stock is a problem of importance. Here the churning and heat conditions do not exist, but in adopting such bearings and the greater capital cost the operator is expecting much lower maintenance costs; anti-friction greases are here called for which can be packed in bearing assem-

bly and so allow the vehicle to run with small attention until overhaul, which may be anything from four to eight years later. Any discussion of grease in relation to its use in the ball and roller bearings of the railways inevitably leads to questions on the most suitable types of grease and consistency ranges in relation to a number of factors, not least amongst which are compatibility and life.

Grease technology has shown some remarkable advances over the last ten years in the search for compositions capable of withstanding high temperatures for sustained periods whilst still essentially retaining their mechanical stability. A grease which is multi-purpose in its application has also been the goal of major manufacturers and, to the extent that the necessary types of grease are being reduced, this has already been achieved. Assembling these desirable qualities into grease has involved turning to the more stable paraffinic oils, high quality fatty acids, and new thickeners of the lithium, calcium complex, or treated clay types; the latter type are commonly used for extremely high temperatures, above 125° C, although there appear to be limitations in the speed and lower $d_m n$ values and in the 200,000 range are more appropriate. All these thickener combinations are water insoluble, and additional attention has been given to rust inhibition; in this connexion recent lithium grease developments with a water-soluble inhibitor seem to be particularly justified for anti-friction bearings.

The compatibility of differing grease compositions will become an increasing problem with the more extreme bearing conditions to be expected. Generally, if branded greases are of the same type their performance characteristics will not appreciably suffer when co-mingled, but with differing types this is not necessarily so, and there is enough evidence to show that such important properties as the mechanical stability and dropping point of the mixture may, in fact, be inferior to either of the two components. This is a point in favour of simplified inventory at the depot, and in any event compatibility data should be obtained on the differing brands likely to be employed.

No. 2 consistency greases (worked penetration 265–295) are the most widely used and best suited for general purposes. However, for double-sealed type or high-speed traction motor bearings the stiffer No. 3 consistency has been recommended, whereas for multiple row railroad journal bearings the American Association RR Specification of October 1952 specifies a 340–370 worked penetration.[5] Opinions differ on the necessity for such consistency ranges and more performance data on differing (composition) greases in equipment are needed before absolute adherence to these can be said to be justified. There is a consensus of opinion which leans towards the No. 2 consistency range as being more suitable for modern traction motor bearings.

As with diesel engine oils the oil companies can also supply assistance to the railways through their facilities and experience on the subject of grease lubrication service. Premium quality greases, such as the lithium soap type, undergo a wide variety of performance tests both within the oil companies' laboratories and those of the major ball and roller bearing manufacturers; indeed one of the major problems to the grease manufacturer these days is to produce a reasonably restricted range of products which will meet all the requirements outlined by the varied rigs at present in use.

Because of this, however, the experience, on which predictions of grease behaviour in varying circumstances may be made, is very extensive; sufficient to offer sound advice on the effects of temperature or $d_m n$ change. Checks on grease condition when considering replacement are again the subject of wide testing supported by experienced interpretation, and the railways can be assured that grease technology has advanced sufficiently to justify a reasonable optimism that all their future demands will be met.

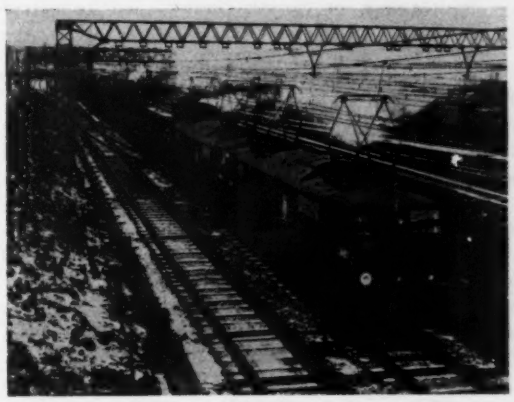

FIG 7

DOUBLE HEADING WITH BO-BO 1740 H.P. ELECTRIC LOCOMOTIVES BUILT BY BRITISH RAILWAYS IN CONJUNCTION WITH METROPOLITAN-VICKERS FOR THE MANCHESTER–SHEFFIELD OVERHEAD WIRE SECTION

The electric locomotive of the future will be a high voltage machine. Three or four rail electrification systems limit the voltage to approximately 600, hence the higher voltage systems will employ overhead wire and pantograph pick-up (Figs 7 and 8). Two important sections of British Railways are already laid out with this system operating at 1500 volts, and early experience shows that there is a very real lubrication problem between overhead wire and pantograph pan.

The overhead wire is copper and the pantograph pan, which often consists of copper strips secured transversely across the line of travel, are thus of the same material.

Without lubrication the copper strips may have a

life as short as 6000 miles, and in terms of main line operation this is equal to only seven return trips from London to Glasgow. Substantial improvements have resulted from spacing the pantograph copper strips so that a channel, of width approximately the same as that of the strips, is left between them. This

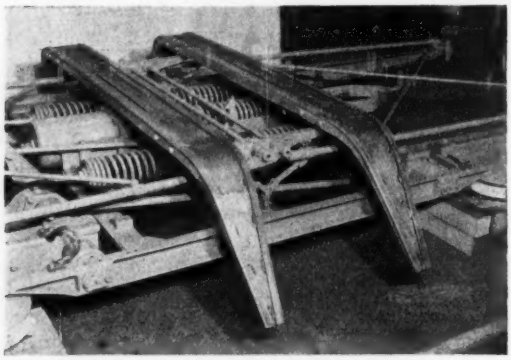

FIG 8

PANTOGRAPH PAN, IN RETRACTED POSITION, SHOWING ONE ARRANGEMENT OF COPPER STRIPS AND LUBRICANT CHANNELS

is filled with a lacquer material. The disadvantage of this method is the length of time required to prepare the pans, as the lacquer has to be applied in successive layers. Allowing for drying time, this method takes several days.

Other products employed are stiff but tacky greases and microcrystalline graphite wax.

The use of carbon strips in place of copper is exercised quite widely on the Continent, but naturally incurs considerable labour occupation on strip renewals. Steel strips, with lubrication, have also been tried.

A final solution will no doubt mature during the course of increasing experience. If a satisfactory lubricant can be developed there is a strong case in favour of metallic strips; failing this, however, the carbon strips may show an overall economy in dealing with this costly problem.

FUTURE DEVELOPMENTS

In countries where the ratio of diesel fuel and fuel oil to electricity costs is in favour of the former power source, combustion engines of one sort or another will no doubt be used in the majority of prime movers, but in Europe this is not the case and, as has been stated previously, electrification is the long-term objective for dense traffic areas and important trunk routes.

It is not surprising, therefore, to find active interest being shown in dual fuel and free piston engines for main line traction, particularly in the U.S.A.

DUAL FUEL ENGINES

It is known that in the U.S.A. experiments are being carried out whereby an engine can be run for the majority of its life on residual fuel under high load conditions, but when light load conditions appertain, such as during stops at stations, the engine is switched to normal distillate fuels, since under such load conditions erratic combustion takes place on residual fuels. In view of the use of residual fuels with such engines, it is evident that detergent lubricating oils will play an increasingly important part in obtaining reliability.

It is considered that this development will be less applicable to shunters and railcars (Fig 9) because of their shorter trips and more frequent light load conditions, and in view of the relatively short-term nature of diesel-engined main line locomotives it is unlikely that this development will be adopted in the U.K.

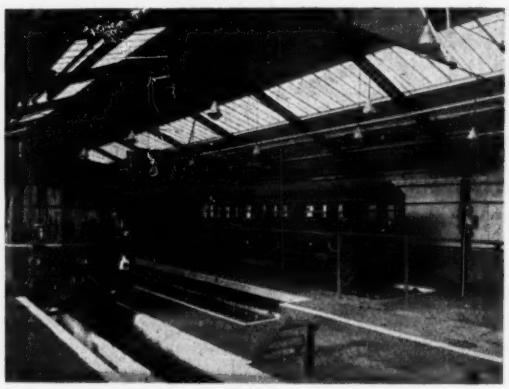

FIG 9

RAILCAR IN DEPOT AT BRITISH RAILWAYS, EASTERN REGION, LINCOLN

FREE PISTON ENGINES

At present there are only two free piston engines commercially available—the SIGMA GS-34 and the Muntz GS-75 units of approximately 1000 and 360 h.p. at the turbine shaft respectively.

The free piston engine has a wide potential power and service range of application. An experimental railway unit has been built by Renault using a GS-34 1000-h.p. engine. This has been in service on the Paris–Cambrai line since 1953. General Motors developed an adaptation of the GS-34 unit for a twin-engined locomotive for that stronghold of railroad gas turbines, the Union Pacific line, entering service in 1957.

Reliability of this power unit remains to be proven. Some initial troubles have been encountered due to high wear rates in the power section of the engine,

although recent modifications to cylinder and piston ring design and metallurgy, together with provision of more uniform oil feed, are understood to have eased this wear problem.

For traction purposes, when reliability is established, the free piston engine has certain advantages over the diesel engine, as below:

(1) Smaller size and weight for a given horsepower output.

(2) Free from vibration.

(3) Can burn residual and residual-distillate fuel blends without modification.

(4) Can be arranged conveniently in multiples to cover a wide power range, resulting in ease of maintenance.

The traction feature of variable power output, however, indicates that overall efficiency is somewhat less than the diesel engine, but this is more than offset by the use of cheaper fuels. Development work to date indicates that a Supplement I level detergency oil, SAE 40, is required. It has also been found advantageous to employ anti-oxidants which provide the combined benefits of oxidation resistance and mild E.P. characteristics.

It is unlikely that the need for independently powered locomotives will be entirely displaced by electric traction in Europe; therefore, it is probable that the free piston engine has an interesting future on both sides of the Atlantic.

CONCLUSIONS

The following broad conclusions can be drawn from the data and discussions in this paper:

(1) The long term trend of railway modernization in the U.K. will be towards electrification rather than dieselization. The dieselization programme is considerable, however, and although main line diesel locomotives will find only short term use, diesel shunters and railcars should have continued application.

(2) Quite apart from technical considerations, the above factors are of considerable importance to the petroleum companies in planning their lubricant and fuel programmes for the railways.

(3) No entirely new lubricating problems will emerge from the railway modernization scheme, and existing experience on differing power components can be applied to these requirements.

(4) For diesel crankcase lubrication the main work to date has been confined to finding out the required quality level for particular applications, such as main line, shunters, and railcars. Selection can be made from the already adequate range of quality levels, such as Regular, MIL-L-2104-A, and Supplement I.

(5) Certain lubrication requirements have arisen as a result of the use of hydraulic transmissions.

(6) In the traction motor field, greases must be capable of dealing with the demands of increasingly high $d_m n$ value bearings. The indications are that recent advances in the use of water insoluble fillers, principally lithium to date, will enable the technologists to do this. More experience in this field is needed, however, to relate performance with composition.

(7) A high degree of co-operation between the railways and petroleum companies is required, not only to establish satisfactory performance levels of the various lubricants themselves, but to ensure that the extensive experience, already available in lubrication service, is used to full advantage. Laboratory data and operational practice must be closely allied to develop the most economic and practical schedules.

ACKNOWLEDGMENTS

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APPENDIX

INTERPRETATION OF USED OIL ANALYSIS DATA

(1) *Specific Gravity*

If the gravity is lower than the new oil this indicates either or both of:

(*a*) fuel dilution;
(*b*) lower gravity oil used for make-up.

If the gravity is higher than the new oil this indicates one or more of:

(*a*) oxidation;
(*b*) insolubles present;
(*c*) metallic soaps present;
(*d*) water;
(*e*) higher gravity oil used for make-up.

Little change in gravity indicates either:

(*a*) oil condition satisfactory, or
(*b*) oxidation or insolubles effects offset by dilution.

In view of the foregoing possibilities it is evident that specific gravity will have to be studied in conjunction with other analysis.

(2) *Viscosity*

If the viscosity is lower than the new oil this indicates either or both of:

(*a*) fuel dilution;
(*b*) lower viscosity oil used for make-up.

If the viscosity is higher than the new oil this indicates one or more of:

(*a*) oxidation;
(*b*) insoluble present—insolubles in gasoline engine oils have little effect on viscosity, but sooty contamination in diesel engine oils has more effect on viscosity;
(*c*) higher viscosity used for make-up.

Little change in viscosity indicates either:

(*a*) oil condition satisfactory, or
(*b*) oxidation and insolubles effects offset by dilution.

(3) *Fuel Dilution*

Gasoline Engine Samples.—The dilution is the amount of gasoline removed from the used oil by distillation. For interpretation purposes:

(*a*) 2–4 per cent dilution is usual but undesirable, and 5 per cent is not unusual in cold weather.
(*b*) 6–7 per cent dilution is frequently encountered under about town " stop and go " conditions.

Diesel Engine Samples.—Owing to the higher distillation range of diesel fuel, it is not possible to separate this from the used oil by distillation. The percentage dilution is approximated by comparing the viscosity of the used oil with that of the new oil, but it is obvious that other factors, such as insolubles, will influence the viscosity of the used oil and hence the approximated dilution. Also mixtures of used oils are unsuitable for dilution estimation, since the viscosity of the mixture without diluent is unknown. However, the flash point is helpful in detecting dilution in contaminated samples.

Thus an approximated figure can be quoted with confidence only if the insolubles content is low and there is a reduction in flash point.

In general:

(*a*) Little or no dilution should be present in a used diesel oil.
(*b*) 5 per cent dilution level does not significantly impair the lubricating oil quality, but denotes faulty mechanical condition.
(*c*) Dilution in excess of 5 per cent may lower the viscosity of the oil to the extent that unsatisfactory lubrication results.

(4) *Flash Point*

As indicated in Section (3), flash point may reveal the presence of dilution but not the amount, but it is necessary to know the flash point of the new oil as well.

In general:

(*a*) Reductions up to 25° F in flash point are common but not significant.
(*b*) Reductions over 30° F in flash point denote faulty engine or operating conditions.
(*c*) An increase in flash point may occur with low viscosity oils, and this denotes that high operating temperatures have driven off lighter fractions of the lubricating oil.

(5) *Colour*

Colour is not a reliable basis for an opinion on used oil condition.

In general:

(*a*) Clear oils indicate good engine and filter operation when using non-detergent oils, but suggest loss of additive with detergent oils. A clear oil is generally low in insolubles, but might have oxidized appreciably.
(*b*) Used detergent oils are normally dark or black, and the same appearance is often encountered with non-detergent types. This appearance is not a guide to the amount of insolubles present, which may be negligible.

Detergent oils darken rapidly during service because of their ability to hold insoluble carbonaceous contamination in a finely dispersed and harmless form.

In the case of non-detergent oils, black colour is indicative of ineffective filtration.

(6) *Insolubles in Pentane*

Insolubles in pentane include carbon (combustion soot), oxidation products, and ash-forming compounds such as lead (from gasoline), metals from engine wear, dirt (silicon), etc. Individual circumstances can show that some of the values given below are conservative:

(*a*) Up to 1 per cent insolubles is considered satisfactory for non-detergent oils and oils up to 2-104-B detergency level.
(*b*) Up to 1·5 per cent pentane insolubles is satisfactory for MIL-L-2104A, DEF/2101-A, and Supplement I oils.
(*c*) Based on limited experience up to 2 per cent pentane insolubles should be satisfactory for Supplement II oils.
(*d*) Pentane insolubles exceeding the levels indicated in (*a*), (*b*), and (*c*) above reflect too long usage of the oil or unsatisfactory engine or operating conditions. It may also reflect oxidation of the oil.

(7) *Insolubles in Benzene*

Benzene insolubles include all components present in pentane insolubles with the exception of oxidized products. Thus the difference between pentane and benzene insolubles indicates the amount of oxidation products present.

In general:

(*a*) When this difference between pentane and benzene exceeds 0·5 per cent this indicates appreciable oxidation.
(*b*) For normal purposes, benzene insolubles are not carried out on used oils containing less than 0·5 per cent pentane insolubles, since the results are not significant.

(8) *Ash*

Ash includes all non-combustible materials present in the oil, such as additives used in the oil, metallic wear particles, dirt (silicon), and lead compounds from TEL decomposition products in the case of gasoline engines.

The following generalizations give a guide to the interpretation of results:

(a) *Diesel Engines*

(i) An increase in ash content of up to 0·2–0·3 per cent is acceptable.
(ii) An increase in ash content above 0·3 per cent is undesirable.
(iii) The limits in (i) and (ii) above apply primarily to iron and other engine parts metals. If silicon (dirt) is an appreciable part of the ash, then only appreciably lower ash figures are acceptable. Less than 0·1 per cent silicon can cause heavy wear.

(b) *Gasoline Engines*

(i) An increase in ash content of up to 0·8 per cent is acceptable, provided this is mainly attributable to lead compounds from the gasoline. Not more than 0·3 per cent increase is desirable from foreign ash compounds other than lead.

An emission spectrograph should preferably be used for analysis of ash, and the results are generally reported in the following manner:

	Concentration in the ash
Major	10–100%
Minor	1–10%
Trace	Less than 1% and not normally reported

It is possible, by using the logarithmic sector technique of spectrographic analysis, to determine actual percentages of elements present to within approximately 5 per cent. However, this is a somewhat tedious method and it is more usual to relate major and minor proportions to the percentage of ash present.

An increase in iron content may indicate wear of piston rings, cylinders, crankshaft journals, gears, etc., and high chromium content may indicate liner or ring wear or water leaks (when inhibitors are used in coolant); a high copper content may indicate failure of connecting rod bearings, thrust washers, and other alloy bearings, and a high silicon content is indicative of contamination by airborne dust.

(9) *Water Content*

(*a*) In general, no water should be present, and the presence of a small amount of water indicates either a cooling system leak or may result from condensation in the engine due to cold operation.

(*b*) The presence of more than a trace of water during warm or hot operating conditions is strong evidence of a cooling system leak.

(*c*) The presence of water accelerates the formation of emulsion sludges and foaming, and may also cause bearing failures or other harm in an engine.

(10) *Neutralization Number*

Neutralization Number is commonly thought of as being related to acidity; it may, on the other hand, be used to express alkalinity, a condition that can be imparted by additives of a certain type. It is possible to differentiate between weak and strong acids and weak and strong bases, the Total Acid Number (TAN), commonly called the Neutralization Value (N.V.), being the total value of weak and strong acids present, and the Total Base Number (TBN) being the sum of the weak and strong bases present.

Whilst the Neutralization Value (TAN) may give useful information [6] regarding interval changes in an oil during use under oxidizing conditions, it should be recognized that no consistent relationship exists between Neutralization Value and bearing corrosion or engine deposits and wear. Nevertheless, a high Neutralization Value is undesirable because of the possibility of harmful effects on bearings and formulation of troublesome engine deposits.

The Neutralization Number (TAN or TBN) of an oil is greatly influenced by additives, as well as by extraneous contamination in the form of combustion soot and other decomposition products. The effect of additives depends on their nature and the amount present; whilst non-detergent oils normally have low neutralization numbers in their unused state, some additive type oils have appreciable Neutralization Numbers, on either the acidic (TAN) or alkaline (TBN) side, because of the additive effect. In the case of unused oils which appear acidic, this is always entirely due to the presence of weak acids, no strong acids being present, and these weak acids are considered harmless; in fact, this acidity is often "pseudo-acidity" due to the amphoteric nature of certain metallic anti-oxidants present in oils containing basic detergent additives, *i.e.* metallic salts, which can react with either a base (such as KOH) to give a TAN (comprised entirely of weak acids) or an acid (such as HCl) to give a TBN.

Since entirely satisfactory unused oils can have a TAN, it is considered more desirable to examine a used oil in terms of an increase in TAN, with some attention being paid to strong acids if present.

All of the factors pointed out above must be given consideration when interpreting the results of Neutralization Number, and in addition these results should also be considered in conjunction with other analytical data, such as pentane and benzene insolubles, viscosity increase, and fuel dilution. For these reasons it is difficult to offer generalizations regarding this subject; however, the following may be broadly applied to used lubricating oils:

(1) Neutralization Numbers (TAN) up to 1·5 are considered satisfactory for straight mineral and non-detergent oils.

(2) Neutralization Numbers (TAN) up to 2·0 are considered satisfactory for detergent type oils.

DISCUSSION

C. C. Inglis: I think the best thing is to refer to one or two points that strike me immediately from the user's point of view. The first is the table showing the groups of engines—the shunting engine, the main-line engine, and the railcars. There is another group which should be added to that. Whether it has any effect on the lubrication problem, I leave to the authors, but it is the inter-city diesel. The kind of things I mean are the Hastings diesels. These are 12-coach trains, with four units of 500-h.p. engines above floor, with more or less standard electrical motors. It has been a very great delight to everybody that they have been running like a clock, with a very low failure rate. I sincerely hope that this particular duty does not need a special oil, but it is nevertheless a somewhat different duty from any of the others.

The authors give two tables, one of which defines the switching service in hours, and the other refers to shunting service in miles. From the oil manufacturer's point of view, which is most useful, the duty of the engine in hours or miles?

There is a reference to this question of testing lubricants. I can assure you that we are very much alive to this, and the Railway Research Department have a number of subsidiary chemical research establishments dotted all over the country, which give a chemical service for various purposes and are taking this matter seriously. We are buying a spectrograph, we know all about spot tests, and our technicians know quite a lot about lubricants and are in touch with the various products and problems. It is a question of extending that knowledge round the railway. We are very conscious of the importance of checking lubricating oils and are getting down to it.

In regard to reclamation of oil, London Transport has examined the economics of this. The economics generally fall down when the costs of handling and transport are taken into account.

The authors refer to the tenacity of lubricants causing non-rotation of geared wheels. Does this mean that the grease is so sticky that it has resisted the full adhesion of the wheel on the rail, which may be 25 per cent of the weight? I think that what in fact has happened is that the towing vehicle has accelerated very rapidly and it is the stickiness of the grease combined with the inertia of the armature that has caused the flat, or the momentary slipping of the wheel.

I would just like to say a word about electric traction and flexible drives in particular. The transmission of all types of diesel and electric locomotives is a vital part, and a good engine can be marred by a bad transmission. With increasing loads and speeds, the flexible transmission, where the electric motor or hydraulic parts are suspended on the frame and are connected to the driving axles by a flexible mechanism to allow for wheel movement, is coming more into use and will undoubtedly

have lubrication problems of its own. I would also hazard a guess that rubber is to be increasingly used in conjunction with mechanical parts, and this will introduce problems of lubricants which will not affect rubber or a rubber that can stand lubricants.

Turning to the electrical side, current collection from the overhead wire is a very complicated matter, and there is much more to it than lubrication. There has not been much experience of 50-cycle traction, but there has been quite a lot at 25 and $16\frac{2}{3}$ cycles/sec. Whether the difference in frequency will alter the current collection problem, I do not know, but the British Transport Commission is very conscious of the problem and is taking steps to solve it. In addition, the contact wire on 25 kV is much smaller than that on 1200 or 1500 V and therefore the wear of the contact wire becomes all the more important.

I think that this multiplicity of oils is really getting too much. The paper makes reference to this—there is a grade for this, that, and the other. I do not know the problems intimately, but there is one thing I do want to suggest, and it is this: suppose one could lubricate an engine with a fuel oil; that would be a very good thing. Or, alternatively, suppose one could fuel the engine with a lubricating oil; that would be a very expensive thing. Why are lubricating oils more expensive than fuel oils? As an amateur in the subject, I guess it is because one wants the oil to last under difficult conditions; therefore additives are put in to deal with sludging, contamination, and so on. What I would like to know is this: supposing the lubricating oil was intended to be in the crankcase for only three or four hours, and in the meantime it was being consumed, how much lower quality lubricating oil would you use, and would it come anywhere near the cost of the fuel oil? The engine would then be eating its own by-products.

I would like to know whether the idea is fantastic or whether it is worthwhile investigating at the present time as an ultimate objective.

W. B. Broadbent: Mr Inglis' remarks are a practical indication that our desire for co-operation between railways and oil industry appears to be well-rooted already.

The inter-city diesels on the Hastings line, and also the Hampshire diesels, which I believe are the same type of vehicle, are rather difficult to classify. I think British Railways classify them as railcars, whereas in actual fact they have an above-floor mounted supercharged six-cylinder engine of a horsepower range uncommon to any other, whether it be a locomotive or a shunter. Shall we just agree that these are an exception in the grouping, but not an exception for lubrication? As supercharged engines, they react favourably to superior lubricant, and no doubt their reliability is to some extent based on correct lubricant selection.

The second point was that of the switching or shunting duties being represented in hours in one table and miles in the other. The practical difficulty is to get an accurate representation of either figure in traction duty, and whichever seems the most likely, that is the one we like to use. It was not until diesel shunting locomotives, with mileometers, came on the tracks that steam engines, which had been allocated an arbitrary mileage figure of 5 m.p.h., were, in fact, found to be doing approximately 1 m.p.h.; hence a time basis for engine duty is preferred.

In regard to wheel slip, this has certainly been a problem in very cold weather, but just how it starts—whether it is purely due to tackiness of lubricant, or whether it is in part due to the inertia of the moving parts and the effect of the gear ratio, I do not know, but damage has, in fact, resulted to the wheel tread.

With flexible drive there is this difficulty with the rubber components, which are liable to attack by the wrong sort of lubricant.

As to the reasons for cost differences between lubricants and fuel oils, this is essentially due to the costs of the extra refining process undergone by the lubricants. The differential varies according to the extent of the solvent extraction, clay treating, etc., which is applied. The possibility of interchangeability of the lubricating oil and fuel oil is novel and engaging. Fundamentally, however, a fuel oil is a very poor lubricant, and experience shows that, even assuming physical characteristics permit its use as a lubricant, very considerable mechanical damage could be caused in a very short space of time.

J. G. Withers: I agree with the authors that the maintenance of alkalinity in a lubricating oil is not essential to keeping wear down to a satisfactory level. I should like to refer to some tests that we have carried out on two-stroke main-line locomotives, in which the oil had an initial total base number of 3 and was changed at 50,000-mile intervals. We estimated the wear by measuring the iron in the used lubricating oil at intervals during the runs and correcting it for lubricating oil consumption. In the first periods, when the engines were new and running in, the initial rates of wear were some four times the values at the ends of the periods. After about 15,000 miles, the oil samples became slightly acid and reached an equilibrium level with the make-up oil at a low level of acidity, but the wear rate was falling continuously.

In the second period, when the oil was changed, the initial rate of wear was apparently higher. This I ascribe either to incomplete draining or to the dispersion of iron that had settled in the engine by the fresh charge of dispersant lubricant. At the end of the second 50,000-mile periods, the wear had dropped to some 6 per cent below that after the first runs. It was apparently still dropping. The oil acidity in the second periods hovered between slightly acid and slightly alkaline after 20,000 miles.

One of the things I have never been able to explain is why large engines seem to give continuous reductions in wear, almost throughout their life, long after the initial effects of surface conditions, malalignment, etc., have been eliminated. In large marine engines, for example, even when $\frac{1}{16}$ or $\frac{1}{8}$ inch has been worn off the cylinders, the wear rate is still going down.

The main point I wish to make is that it does not seem necessary to have a high degree of alkalinity during the course of a run in order to keep the wear down to a very low figure. The cylinder wear in the case referred to was averaging at about $\frac{1}{1000}$ inch per 100,000 miles, which is quite a low figure for a two-stroke locomotive. This wear figure is the average of all measurements taken in the plane of maximum wear, averaged for the different cylinders and locomotives. I should like the authors to confirm whether that is the procedure they use for their quoted average wear figures.

There is no question that there are many mechanisms by which wear is reduced by a lubricating oil, and in all probability acid neutralization is one of them. There must be others, such as wettability, work of adhesion, and even detergency, because almost invariably a clean engine is accompanied by a low rate of wear.

Shunting locomotives operate entirely satisfactorily on a regular oil, but do not the authors think they would operate even better on a higher quality of oil? The advantages would be wear reduction, extension of oil change period, and simplification in stocking, a point made by Mr Inglis.

The authors state (referring to railcar engines) that the relative prices of fuel and lubricant generally result in the adoption of an SAE 30 lubricating oil. I do not quite understand this, but the meaning I put to it is that the saving in fuel consumption resulting from the use of lower viscosity oils would not be worthwhile. I should have thought that savings in fuel would have been as worthwhile as they are in automotive engines; after all, the engines concerned are very similar.

I am rather surprised that the spur gear drives for nose-suspended motors still present problems. This is a very old drive—it has been in use in trams and motor coach units for many years, and also in main-line locomotives in America and on the Continent. I should have thought that the seal problem could have been solved, or a much more suitable oil found than the bituminous compounds referred to by the authors.

No mention is made in the paper of air filtration. This is particularly important in diesel engines, in keeping wear at a low level. I do not know about British Railways, but track conditions abroad can be very dusty. An oil in an air filter is not strictly a lubricant, but if properly compounded, it can give very substantial improvements in filtering efficiency. Air filtration is, of course, also important in traction motors.

I endorse very emphatically the authors' views on the need for very close collaboration between the oil suppliers and the railways. It is only, of course, by pooling their experience and avoiding overlapping that the maximum reduction in running and maintenance costs can be achieved.

G. A. Dickins: In connexion with the point Mr Withers made as to whether a MIL oil might not give better service with a longer drainage period for shunters, rather than the regular grade that is shown in our table, the short answer is that we do not yet really know. The fact does remain, however, that the service life and the wear that we have been getting with this regular grade in this service is particularly good, and whether or not a MIL oil would show better economics for Mr Inglis, I do not know. It is quite obvious that a MIL level oil is going to cost considerably more, so one has to get a good deal of benefit from the wear and drainage periods to offset that.

W. B. Broadbent: The wear measurements were taken in four positions down the cylinder bores in each cylinder. Our average cylinder wear measurements in the paper are, in fact, the average of the maximum readings throughout the cylinders. The average of the whole lot would be rather less than that.

In regard to the point that the relative prices of fuel and lubricant generally result in the adoption of an SAE 30 grade oil, we had intended to amplify that a little, because we realized it was somewhat ambiguous. The economics rest entirely in the hands of the Government, which determines what the tax rate shall be on fuels as used by motor transport and railways. Whereas it is an economic proposition to use an SAE 20 oil on a bus, with the same engine as that on a railcar, it is no longer an economic proposition on a railcar, because the fuel oil is so much cheaper for the railways than it is for the bus company. Therefore the reasoning is right either way; in consumption one obtains a saving on a railcar in just the same way as one does on a bus, but one does not in cost, because the fuel oil is so much more costly to the road user than the railway.

On the problem about traction gears, in general the oil companies have endeavoured to force this point home with the gear manufacturers, and it does seem that some progress is being made at the moment.

On air filtration we do draw attention to this problem of airborne dirt in our acceptable ash limits, where we bring out the point that silica is a very adverse feature, even more so than ash from wear débris.

L. J. Izard: The first point on which I would like to comment concerns the use of spectrographic analysis of the crankcase oil as an aid to maintenance. The authors remark that experience is required in determining significant deviations from normal metal concentrations. With that remark I wholeheartedly concur, but I would like to point out that according to the experience we have had over the past few years with this method of analysis, variations of apparent significance can be obtained merely by varying the method of taking the oil samples from the engine. I think it is essential to standardize on the method of taking the oil sample from any particular kind of locomotive engine.

I should also like to draw attention to the fact that examination of the iron and silicon content of locomotive engine oil is a very good check on air filter performance and servicing, whilst examination of chromium content is a check on water leakage where chromate inhibitors are used in the cooling water system.

The second point concerns Tables III and IV. The authors refer to an appreciable quantity of insolubles build-up in the oil. In my opinion, the level of insolubles recorded in the tables is in no way appreciable. Figures of a higher level for combustion insolubles are quite permissible, providing sufficient effective additive remains in the oil. This leads me to enquire whether the authors can provide any information on the effective additive content of the samples listed in the two tables, since I cannot see, from the published figures, how the remark about the greater mileage possible when using the oil of greatest detergency can be made.

G. A. Dickins: We did not spend enough time on detailing spectrographic analysis in the paper, although we know what a valuable contribution it has made to the study of wear on railways, not only in the U.K., but in America. We are also grateful to Mr Izard for bringing out this inevitable question of oil analysis sampling and the effect that it has on results. That is checked in our own tables, and we are sure that it is one of the most significant variables in the whole of this type of work. The training in the taking of samples is a most important function on the railway side.

In regard to Table IV, with these particular railcar engine units, we have found that the essential feature governing oil life is that of insolubles and the effect they have on engine cleanliness. The overhaul period varies from region to region, broadly between 75,000 and 100,000 miles at the present time; various attempts are being made to push it up above the 100,000-mile mark. However, the length of time one can maintain the engine in a clean condition with a maximum mileage between oil change is the aim, and the effect of additive depletion in the short periods during which the oil is in service does not appear to enter into it with these railcar units.

T. Rhead: The authors have dealt with the lubrication of the diesel engine and certain electrification aspects, but they have given hardly any attention to the problems which may arise in connexion with the lubrication of axle-boxes. I am thinking particularly about axle-boxes of the plain-bearing type, which we may have with us for a very long time. Obviously, if the axle-boxes are not going to be capable of standing up to the new speeds, which are desirable with the modernization plan, the whole scheme will fall down.

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I wonder whether the authors have given any thought to this, with particular reference to freight vehicles rather than passenger. We know that a number of roller-bearing boxes and alternative types of oil-lubricated plain-bearing boxes are being tried at the moment, but it is likely that we shall have a large number of pad-lubricated plain-bearing axle-boxes with us for a long time, particularly on certain types of freight train, and they will be called upon to run at probably double their present speeds.

W. B. Broadbent: It should be pointed out that the initial programme for the modernization of freight stock takes account of introducing 80,000 anti-friction bearings and 15,000 of the isothermos type, which are essentially high-speed bearings. We would have thought that in the early stages the answer would have been largely one of traffic organization to see that the high-speed vehicles were on the high-speed trains. However, if it comes down to a question of making the existing vehicles available for high-speed duty, it will possibly be found necessary to employ the rape-blended carriage axle oils. It is more of a design feature and essentially one for the modernization programme.

C. C. Inglis: I would like to remind Mr Rhead that there are 1¼ million wagons on British Railways, each of which has at least four bearings. So that even tens of thousands of bearings are a small proportion of the total. It will take a long time to replace all these bearings with anti-friction bearings, even if we want to, and as high-speed merchandise trains are coming more and more into the picture I am very glad that Mr Rhead has raised the point, because the lubrication of this type of bearing is very vital to efficient railway operation.

The problem of the plain bearing, whether we like it or not, will be with us for many years.

A. S. Freeman: In regard to the list of used oil analyses given in Table VI, I feel that specific gravity, in this particular context, is rather an unnecessary determination, and it is noted in fact that the authors recorded only the specific gravity on used oils in Tables I and V. Their interpretation of changes in specific gravity, as given in the Appendix, is adequately and more accurately covered by the other tests on the used oil, which in fact they describe.

In regard to the use of the emission spectrograph, it is felt that the analysis of the ash as major, minor, and trace constituents, as described in the Appendix, is not really sufficiently precise and detailed when dealing with routine analysis of used oils from main-line locos, and a more detailed analysis down to parts per million is very desirable in order to be able to trace changes in wear patterns of metallic constituents entering the oil, and also material such as silicon from airborne dust entering from outside. I would like to emphasize that I think the determination should be conducted down to parts per million in order to follow closely these changes in concentrations of materials.

The other tests which are important on used oils for the main-line engines are the viscosity, insolubles, and flash point. The flash point is a very reliable indication of fuel dilution, and whereas the authors have adopted the open flash point, we prefer the closed flash point. With this test a drop of about 40° F is not considered significant, and if the reduction is higher than 40° F it is customary to carry out an ordinary fuel dilution test by the old steam distillation method. Evidently the authors do not seem to favour this method, but in our opinion, this test, which I believe was abandoned by the IP as a standard method some years ago, is still valid and reliable when used with discretion, bearing in mind the characteristics and composition of the used oil, which, after all, are, or should be, known to the oil supplier!

G. A. Dickins: We still believe there are many great difficulties in determining the amount of diesel diluent, and we use the test which Mr Freeman described with some reservations. To some extent, a lot of these tests are matters of sound interpretation; different laboratories have different means of carrying out their tests, but they ultimately come to much the same answer.

G. M. Barrett: The authors state that the present trend is to rate the traction diesel engine conservatively, although they go on to refer to main-line units with engines having a b.m.e.p. of around 165 p.s.i. The b.m.e.p. provides a measure of the maximum and mean pressure to which the gas rings have stood up, but it is less reliable as an indication of the thermal stresses to which the piston and rings are subjected. Ricardo has used the b.h.p. per sq. in. of piston crown area as a criterion for estimating the degree of positive cooling required for the piston of a diesel engine. For the various makes of supercharged engines which are included in the British Railways pilot order for main-line diesel locomotives, the b.h.p. per sq. in. of piston area ranges from about 1·3, for some engines of British design, up to 2·4 in the case of German engines. By contrast, in the case of bus and lorry diesel engines made by the two leading manufacturers in Britain, the figures for the top automotive rating are only 1·20 and 1·28 b.h.p/sq. in., which suggests that engines for main-line locomotives tend to be highly rated. This is to be expected, because diesel locomotives are relatively heavy machines and produce only about half the d.b.h.p. of a straight electric locomotive of the same weight, and hence there is a need for diesel engines of high power to weight ratio to improve this disadvantage.

Later, the authors, referring to experience in the U.S.A., say that most diesel engines, made by a relatively small number of suppliers, run most economically on MIL-L-2104-A type detergent oils. Here it is important to remember that detergency is not the only requirement and that other properties, such as the ability to lubricate and protect bushings and bearings of various special alloys, are equally important. With regard to the oil life, which is said to be longer in the U.S.A. than in the U.K., differences in fuel sulphur content, size of initial oil charge, and rate of oil consumption, which all affect the rate of additive depletion, could be compensated for by selecting the initial additive concentration. However, the build-up of the soot burden, which may eventually be the controlling factor in deciding on an oil change, is a function of two main factors, the combustion conditions in the cylinder which produce the soot, and the efficiency of the lubricating oil filters which remove some of this contamination. In these diesel engines of American design the interaction of these two factors certainly does result in very extended oil life.

There is a reference to the trials on some U.S. railways of locomotives adapted to burn residual fuel at high loads and distillate fuel at low loads and idling. Such locomotives have been loosely called dual-fuel locomotives in the U.S.A., but I would like to make a plea to engineers and the technical press in Britain not to follow suit. The dual-fuel engine is now a well-established term to describe an engine which can operate at will, either as a conventional diesel, or as a gas engine in which the aspirated mixture of air and gaseous fuel is inflamed following the compression ignition of a charge of liquid

fuel which is sprayed through the injector in the usual way. The uninitiated might imagine a dual-fuel locomotive as a vehicle with an enormous gas bag on the roof, and the British loading gauge is tight enough already. Therefore I would suggest that we call them bi-fuel locomotives, which avoids any ambiguity. However, I would agree with the authors that conditions in Britain would not appear favourable for similar developments in the use of residual fuels. Even main-line express locomotives in the U.K. are worked at a surprisingly low average load factor, which accounted for the unfavourable operating results with the two gas-turbine locomotives on the Western Region.

Lastly, in listing the advantages of the free-piston engine, the authors omitted to state that there is no real need for an electric transmission which wastes about 20 per cent of the b.h.p. of the prime mover. The stalled torque of the gas turbine can be designed to be four times the full-speed torque, so that a mechanical transmission comprising a two-speed gear, which is changeable whilst running, is all that is required to provide a desirable tractive effort/rail speed curve. A 2000-h.p. locomotive on these principles is now nearing completion in France.

R. M. Williams: The authors state that the long-term policy of railway modernization in the U.K. will be towards electrification rather than dieselization, and that the main-line diesel locomotive will find only a short-term use. It would be of interest to know what the authors consider to be a short term.

Experience overseas has already proved that the diesel locomotive can act as the spearhead of electrification, that they can be used very profitably on main lines which are planned for electrification, and afterwards be used to operate on the connecting links between the electrified network and on lines which will not be electrified in the foreseeable future. Considering the size of British Railways, and the amount of electrification planned for the next 10 to 15 years, I think there is plenty of scope for the main-line diesel locomotive in the U.K., particularly in view of the earning capacity of this type of locomotive.

The experiments referred to by the authors on the lubrication of electric traction pantograph pans is most interesting, and I wonder if they propose similar lubrication for high-voltage electrification pantographs. The authors refer to the considerable labour occupation on the renewal of carbon contact strips. The cost of the strips and their renewal must be compared with the cost of the catenary contact wire and its renewal. This contact wire is perhaps one of the most expensive wear components on an electric railway, and all measures to protect this wire should be taken. With high-voltage electrification, the overhead construction is much lighter, the pantographs are lighter, and contact pressures lower, and it is wondered if the advantage of lubrication may be outweighed by any lubricant remaining on the contact wire causing dirt to adhere, and so promote excessive corrosion, particularly in industrial areas.

The only application known for steel strips on the Continent is a scraper-type strip for removing ice in winter, but this is not favoured, as it tends to damage the contact wire.

The authors refer to the size of British Railways, its route mileage as compared with American railroads, and to the difficulty of making a successful application of laboratory analysis control on used lubricating oil samples as against simple field controls. They also refer to sampling, analysis, and interpretation techniques. Regard must be paid to work undertaken on crankcase lubricating oils by the chemists in all railways, and to give an example of this type of control the used lubricating oil analysis from the Dutch/Swiss Trans-Europe expresses, which operate between Zurich, Amsterdam, Brussels, and Paris, is being carried out at the Netherlands Railways Laboratories in Utrecht. Oil samples are taken from the trains at Amsterdam and information forwarded as required. It is a common complaint that distance is an over-ruling factor for the organization of crankcase oil controls, but the example quoted shows that it is possible to organize such a control for trains operated by five railway companies in five countries.

I believe there are to-day ten chemical laboratories on British Railways which regularly undertake the analysis of used crankcase lubricating oils, and they have been doing this for many years.

G. A. Dickins: Mr Williams raised the question of railway chemists' knowledge of oil control, and cited the modern laboratories of the Dutch Railways at Utrecht, where they do give this incredible service from the one point. He mentioned one claim in particular, which I think should be broadened to include the whole of their railway. They do, in fact, gave a 48-hour service to every diesel unit on that railway, and they examine samples according to the type of work being performed, main-line, shunting, or railcar, at periods between three days and a fortnight.

We have not as yet accumulated conclusive data on overhead line wear as related to low and high voltages and pantograph pan strip wear, but fully agree this costly problem is a fundamental factor in the economy of electric traction.

C. C. Inglis: Mr Williams made some very good points. Dieselization is regarded in some quarters as a forerunner of electrification. We are certainly not going to buy expensive main-line diesel engines costing £100,000, say, and throw them away after a few years. The problem, therefore, is that they must be suitable for running at a later date on other lines. In general, the mileage one can get out of modern types of locomotives is limited more by the traffic than by the engines, and this is an important feature of the economics of motive power.

J. H. Harris: The paper refers to the increased bearing diameter required by increased load and limitations imposed by design, with speeds likely to be reached perhaps for long periods, indicating the possibility of churning of the bearing lubricant. With the additional tendency to slumping of grease from end covers accepted as inevitable in railway traction conditions, this can be quite a serious matter at high bearing speeds. By churning we mean continuous circulation of the lubricant in the bearing, and while this undoubtedly gives excellent lubrication to all parts, the temperature rise that can thereby be occasioned can result in early failure of even the most highly oxidation-resistant type of lubricant, followed by failure of the bearing.

Reference is made to accurate methods for ensuring the optimum quantity of grease packing, and it would be most welcome if the authors amplified this remark, since the question of packing is very relevant to slumping and churning problems, as well as to correct grease lubrication of rolling bearings, where the disposition of the grease, as well as quantity, is equally important.

The use of relief valves, which can to some extent cater for over-packing, is wise, but the indication that grease of No. 2 N.L.G.I. consistency seems to be the best proposition is debatable, particularly in relation to slumping

and vibration. The work reported in the paper " Yield Stress as a Factor in the Performance of Greases," by Evans, Hutton, and Matthews, suggests a useful means of preventing slumping potentialities at anticipated operating temperatures, and there is some indication given in this paper that something of the order of 17 g/sq. cm. may be a critical minimum value in large bearings at high speeds. Greases of No. 2 N.L.G.I. consistency may be marginal in this characteristic and, so far as is known, the tendency in the U.S.A. for this type of operation is in the direction of No. 3 consistency greases.

The authors cite the A.A.R. Specification of October 1952 relating to axle-box bearings, and the use therein of very soft grease of between N.L.G.I. 0 and 1 consistency, but even here it is believed that the current trend in the U.S.A. is towards No. 3 consistency grease. I wonder if the authors could discuss the basis for their statement that there is a consensus leaning towards grease of No. 2 consistency.

Their reference to the use of lithium-base grease with water-soluble corrosion inhibitor is welcome, as there seem to be the soundest reasons for using greases that will protect bearings against corrosion in railway traction.

The vexed question is raised of addition of grease of types other than that already in the assembly. Although this is much to be deplored, it is a real issue. However, experience has so far shown that the so-called mixing of greases does not lead to the serious consequences which might be predicted from laboratory work on the subject. This may be due to the fact that true mixing does not take place in the bearing housing and that, as far as the bearing itself is concerned, the paper given by Milne, Scott, and Scott of the Mechanical Engineering Research Laboratory at the conference on Lubrication and Wear in October 1957, " Observations on the Movement and Structure of Grease in Rolling Bearings," suggests that in the bearing proper, as distinct from the housing, the lubricant inevitably loses its grease structure due to the breaking up of soap fibres. While therefore not to be recommended, addition of suitable grease—and the operative word is suitable—to a suitable grease in good condition already in the unit would not necessarily lead to failure.

I would like to make one further point on the question of traction gears. Mr Inglis raised this issue of flats on wheels on towed motor cars. I think there was some experience of that in London Transport round about the 1930s, when bituminous bitumen/oil gear compound was used. That was a not uncommon experience in extremely cold winters.

G. A. Dickins: It is very difficult in a short time to discuss the compatibility of greases. What Mr Harris said, in effect, is that there are degrees of performance that are obtainable by intermingling one grease with another. That is our experience, that the mingling of greases, a suitable one with a relatively suitable one, may not, by any means, downgrade the performance of the product to produce a performance failure. However, compatibility work that we have done indicates that, in most cases where there is a significant divergence of composition, one does obtain a downgrading of some of the qualities, but this does not necessarily lead to a failure in the actual bearing itself. We agree with that point wholeheartedly.

Concerning accurate methods of packing bearings with optimum quantities of grease, a great deal of work has been done on this problem by British Railways and London Transport.

Traction motor bearings on multiple unit stock are packed with a weighed amount of grease, 10-oz for the pinion end and 7½-oz for the commutator end, in the case of multiple unit stock with which we have experience. In the case of London Transport replenishment is adopted at the rate of 1¼ oz annually. (See paper by A. W. Manser given to the Institution of Locomotive Engineers, 20 January 1954.)

Axle-box bearings call for larger quantities, obviously, and the amount is dependent on size. With the exception of locomotives, it is usual to run these axle-boxes between overhauls without further addition of grease. This may be for periods in excess of four years.

A. G. Wallis: Reference has been made by Mr Harris and Mr Inglis to the locking of traction gears on electric and diesel electric locomotives during towing operations, the inertia of the armature and its reduction gears being suspected. However, in my experience I have found that these locomotives are invariably towed because the electric motors or armatures are unable to overcome the resistance within the traction gears, a fault which inevitably occurs during cold weather. It would, therefore, seem apparent that it is actually the grease lubricant which had congealed, due to the low temperatures, and has then caused this excessive resistance within the traction gears and the consequent wheel locking.

L. J. Bowyer: With Mr Inglis' permission I would like to amplify his remarks in respect of the service that is given by the Research Department to the Motive Power Department. A Research Department Chemical Services Committee issued in March 1956, for the guidance of mechanical and electrical engineers, a report embodying recommendations for the use of diesel lubricating oils and their control.

However, even before the appointment of this committee, the Area Laboratories of British Railways gave a service to the Motive Power and Mechanical and Electrical Engineer's Departments by examining new and used lubricants.

The BR Chemical Services have for many years examined regularly for the Southern Region the samples of oil taken from the crankcase of D/E shunting locos at their three-monthly examinations and also the mainline D/E locos when they were operating on the Southern Region.

With the introduction of the multi-unit railcar on the Southern Region's Hastings and Hampshire lines, an even more comprehensive scheme of examination has been adopted, whereby the crankcase oil in each engine is examined monthly.

Samples of the oil are taken by the maintenance staff at the monthly examination in a manner prescribed by the laboratory. These are forwarded to the laboratory by passenger train, with as little delay as possible.

In addition to these samples, it occurs from time to time that the daily inspection reveals an irregularity in sump conditions. When such an incident arises, a sample is immediately forwarded to the laboratory, who are advised by telephone that the sample is on the way and should receive priority. With these emergency samples the determination of fuel or other contaminant is carried out and the depot advised of the results within a few hours.

The normal monthly samples are examined on arrival at the laboratory for fuel dilution, and if considered satisfactory in this respect then await their turn as far as other tests are concerned. If fuel is detected in quantity, recommendations of oil change are made.

The record card on p. 203 indicates the type of examination made of these oils. All tests are very similar to those outlined by Mr Dickins.

Our object is to assess each contaminant, fuel, wear products, water, insolubles, etc., and to satisfy ourselves that they are of such an order that the oil is suitable for further service.

Engine No. IH 3699 Unit No. 1011
Motor Coach No. 60015 Depot: St. Leonards

Date sampled, 1957	20/6	4/7	13/8	1/10	30/10	10/12
Lab. No.	2,364	2,531	2,888	3,403	3,700	4,094
Lub. oil top-up, gal	5	15	25	48	58	72
Fuel used, gal	728	2,561	4,813	10,198	12,002	15,547
Engine hours	103	338	467	844	1,077	1,358
Mileage	1,843	5,036	11,702	20,567	28,147	35,198
General appearance	B	B	B	B	B	B
Sp. Gr. at 60° F	—	—	—	—	—	—
Visc. at 70° F (R.S.)	1,428	1,427	—	—	—	—
Visc. at 140° F (R.S.)	169	168	165	171	174	175
Closed flash point, °F	390	405	395	405	405	385
Base No., mg. kob/g.	—	—	—	—	2·5	2·5
Ash sulphated, %	0·91	0·85	0·74	0·85	0·94	0·90
Copper, p.p.m.	10	under 10	18	12	11	16
Iron, p.p.m.	33	32	44	46	69	46
Water, %	—	—	—	—	—	neg.
Fuel dilution, %	<1	<1	prac. nil	prac. nil	under 1	approx 1
Total suspended matter, %	0·46	0·7 (*c*)	0·79	approx 1·0 (*c*)	0·82	approx 1·1 (*c*)
Consisting of: Mineral ash	0·22	—	prac. nil	—	0·25	—
Asphal enes.	0·08	—	0·79	—	0·57	—
Fine carbon.	0·16	—		—		—
Additive depletion	—	—	—	—	M	M

This record card is published by permission of the Assistant Director of Research, British Transport Commission (British Railways Division).

As far as wear products are concerned, we have not as yet emission spectrography available to us and must resort to the more lengthy methods of determining wear products chemically.

It is foreseen that, with the continued development of dieselization, depots may be established where there will be an excessive time delay in getting samples to the existing laboratories. Also, with the increasing number of engines it may not be possible with the existing staff and facilities to carry out such exhaustive examination at monthly intervals. In the light of more experience, however, it might possibly be found unnecessary to examine so frequently.

The assessment of fuel dilution by means of a suitable viscometer and other simple tests will no doubt ultimately be carried out by trained shed staff in the course of the monthly examination, or as may be deemed necessary, and samples forwarded to the laboratory, say, at three-monthly intervals to check on the various aspects that can be carried out only under laboratory conditions.

One of the main disadvantages of shed control is that there are no simple tests that can be used by the shed staff to determine wear products. Examination of the ash spectrographically or chemically can be carried out only in a suitably equipped laboratory.

I hope by this brief statement to have indicated that British Railways are alive to the situation of oil control, and in concluding would say that we are aware of the necessity of a close liaison between supplier and user and that we desire to co-operate in every way.

G. A. Dickins: Mr Bowyer says that he is now doing a comprehensive examination on the Hampshire diesels every month, but hopes to spread that in the future by putting a monthly check in the hands of the motive power people by means of the rolling sphere viscometer. Then a comprehensive examination would be carried out every three months in his laboratory. We are very interested to hear that experience has shown that he can run these main-line type diesel engines for such a long period, without having even a minor analysis done on the oil. That certainly speaks highly for the reliability of the engine, and we would have thought that a more frequent check analysis would perhaps have been a good insurance.

The considerable amount of work carried out at the Ashford laboratory in connexion with diesel engine samples is well known to the authors, who have enjoyed contact and exchanges of views on this and other subjects for many years.

A. T. Wilford: It may not be inappropriate for a few remarks to be made based on experience with buses which have had diesel engines in them for the past 20 years and more. In our time we have examined many thousands of samples of used lubricating oil from diesel engines. We have done so for the purpose of assessing the characteristics and lubricating qualities of a variety of blends and for determining oil change periods, particularly when we started to use detergent-type oils. However, except in the very early stages of diesel engine development, we have not looked at the matter from the aspect of the condition of the oil in the individual engine. We have been concerned almost entirely in getting mass data.

It is fair to say that over the years, apart from the very earliest days, we have never had a case of an engine failure in service which could be attributed to the condition of the lubricating oil. Engine failures in service are in fact very rare, and the average London Transport bus runs for 58,000 miles without a mechanical failure due to any cause whatsoever. Our work on used oils has been for establishing specifications and for determining optimum oil change periods. Carbonaceous suspended matter, *i.e.* insolubles in IP spirit, is of the order of 1·5 per cent; ash contents at the time when non-detergent-type oil was in use were ranged from 0·10 to 0·15 per cent, although for individual engines there would be appreciable variation either side of the figures for both suspended matter and ash content.

We did give thought, following upon information received from the U.S.A. some four or five years ago, to the possibilities of spectrographic examination of crankcase oils, but we have got something like 8000 engines, and it turned out that we should need a battery of spectrographs, together with a very much enlarged laboratory staff. It was apparent, moreover, that nothing useful would be achieved, because we do not get failures in service. If an engine should fail, the worst that could happen would be that 56 passengers, very regretfully, would be delayed for a short time, but this is nothing like what might happen as a result of an engine failure on a main-line railway, when the whole service might be held up for two or three hours.

W. S. Ault: One of the most important points which have emerged is this question of co-operation, with which I would also couple patience. A point which aroused quite a lot of discussion and interest is the choice of the best grades of lubricating oil for continuous service, and possibly also grease service. I feel we ought to draw a moral from the discussion, that it is up to the railways, the oil industry, and the manufacturers of the equipment to make a close, co-operative, and patient study of the data as it comes in, and from that work out the optimum solution, taking all factors into account, and arrive at a sensible and economic solution to the problem of grades.

A vote of thanks to the authors was accorded with acclamation.

CONTRIBUTED DISCUSSION

O. G. Dellacanonica and Lt.-Col. S. J. M. Auld: The authors are much to be commended for having dealt so admirably with the many factors influencing successful operation of internal combustion engines for rail traction. The authors are primarily concerned with British Railways, so there is no need to comment on their view that dieselization is a temporary stage preceding full electrification, nor shall we comment on their classification of engines or the b.m.e.p. ranges for each classification as known in the U.K.

Unless we are misinterpreting some of their remarks, it appears that the authors associate increasing difficulty in obtaining reliable operation with increasing rating of the diesel engines.

Our own experience over the last 12 years or so has been concerned with a gradual increase in b.m.e.p., which, in the ALCO 9 × 10½, 1000 rev/min engine, stands now at 194 p.s.i.

This increase has been made possible largely by metallurgical developments, particularly in crankshafts and bearings, by the use of alloy ring carriers for top piston rings, and by supercharging improvements and aftercooling, resulting in more effective scavenging and combustion chamber cooling.

This increase in engine rating has not been accompanied by decrease in reliability. On the contrary, engines nowadays have far better records than the more conservatively rated units built immediately after the war.

During this period the lubrication requirements have remained practically the same and demand the use of lubricating oils of U.S. MIL-L-2104-A standard and of basically high stability.

With oils meeting this specification, and having satisfactory anti-sludging, *i.e.* cold temperature, characteristics, we have been able to operate successfully with fuels over a wide range of properties, including low cetane numbers and sulphur in excess of 1 per cent by weight.

In our experience the demands on the lubricating oil brought about by poorer fuels are minimized by the temperature control ability of the aftercooler. In effect, at low engine loads, the water in the aftercooler is at a higher temperature than the air and surrenders heat to the air. Compression temperatures at no-load remain practically constant throughout the engine speed range. The demands thus imposed on the oil by the engine operating conditions, particularly on anti-sludging and other low temperature properties, are thus less severe than in conventional, non-aftercooled engines. This, in our opinion, tends to show that the question of suitability of a given oil to a certain type of service and fuel is not simply a question of b.m.e.p., nor can it even be reasonably related to b.m.e.p. as a major variable.

We have, of course, developed an elaborate system of tests to determine whether an engine oil will stand up in service, but final approval and grading is in fact based on successful operation in the field.

The authors make some remarks concerning lubrication service which deserve special attention, and our experience lines up closely with their recommendations. We have endeavoured to establish a system of lubricating oil control consisting of successive and complementary steps. Nearest to the engines themselves, *i.e.* at their operating points, running sheds, etc., we favour the installation of " quick checking " laboratories.

For this purpose we find that approximate viscosity as measured by simple methods, qualitative determination of water by the hot plate method, and comparative determination of solid contamination by the blotter test give a first clear indication of the state of the oil, and may point to certain types of incipient engine trouble.

These tests have the advantage that they do not call for highly trained personnel, and therefore, particularly in far-flung railway systems, they help to keep under control locomotives that may spend quite a number of days and accumulate considerable mileage between consecutive visits to their operating point.

On a division basis or, in smaller railways, on a system basis, central laboratories are needed for full testing of the oil, at least on the lines of viscosity, gravity, flash point, water and sediment, pentane insolubles, benzene insolubles, and ash.

Spectrographic analysis of the ash is also desirable to determine additive concentration as well as the presence of wear metals.

A system so organized yields for a given type of engine on a given service a pattern of variations in lubricating oil properties that results in the possibility of setting up oil and filter change schedules on a time or mileage basis. This simplifies record keeping and pays good dividends in reducing locomotive operating costs.

An unusual variation of properties, particularly respecting dilution, water, pentane insolubles, or ash content, if not explicable by some change in fuel properties, is an indication that something is amiss with the engine and should be investigated. We emphasize the words " the engine " and not the oil.

Along these lines, spectrographic analysis has progressed far beyond the stage of qualitative determination of some important components of the lubricating oil ash. A complete qualitative and quantitative spectrographic analysis, employing as a reference a known standard, may be used to determine an infinite variety of engine conditions. Much of our own experience, for example, was gained with 1750-b.h.p. diesel engines of earlier model, having low hardness crankshafts and soft copper–lead bearings. By selecting as variables copper, lead, iron, chromium, silicon, and aluminium, and determining normal levels, then studying the variation of these levels for known and controlled engine conditions, it was possible to establish scales whereby the condition of an engine, the necessity for an overhaul, a piston inspection, of a bearing change, etc., could be pinpointed within a very narrow range of dates. This proved to be an excellent tool, and with the introduction of hard crankshafts and bearings and other improvements it was possible to establish new basic values for the same purpose. Wear rates, however, became considerably lower with the new engine and follow a more complicated law, so that we must admit that interpretation of spectrographic analysis is becoming more difficult.

In that connexion we have noted with interest the authors' remarks on free piston engines, and share with them reservations on the reliability and wear rates of this power plant under railway conditions.

On a further point on this subject we do not find ourselves in agreement with the authors. The use of free piston gasifiers of the Sigma G-34 type to obtain traction h.p. equivalent to those obtainable with high output diesel engines results in larger and heavier power plants. The freedom from vibration of a free piston gasifier is closely matched by a well-designed diesel engine. In the case of railway vehicles, vibrations originate mostly at the tracks, and anchoring of the power plant to the

vehicle must be made substantial to withstand these vibrations, as well as acceleration and deceleration forces. The free piston power plant therefore has, at the most, in our opinion, only a theoretical advantage in respect of vibration of little practical interest.

Lubrication problems in the free piston engine are considerably greater than in the conventional power plant, and cylinder wall lubrication with supplemental series oils seems to be required if heavy deposits are to be avoided. This point has been covered by G. Flynn, Jr., of General Motors Corporation research staff (" Observations on 25,000 hours of Free Piston Operation," SAE meeting 1956). This is an all-loss type of lubrication and, therefore, very expensive.

The authors, in reply, write: Accepting the requirement of bearing lubrication and protection, oil selection is essentially allied to the cylinder conditions in the diesel engine. We have suggested that b.m.e.p. is given consideration in this respect, and Mr Barrett cited Ricardo's thermal criterion of b.h.p. per sq. in. of piston crown area. Any generalization of this sort is inevitably only the beginning of the story, and before a conclusion is reached the refinements of design which are associated with high power to weight ratios must be taken into account.

Intercoolers, as applied to the ALCO 16-251 engines, ease cylinder conditions at high and low outputs. Similarly, the Maybach MD 330 engine, with a b.m.e.p. of 160 p.s.i. is so provided, as also are engines by SLM, MAN, and MAK, which have b.m.e.p. in the region of 150 p.s.i.

The significance of operating conditions is another important feature, amply illustrated by a British Railways estimate for line service that between 40 and 50 per cent of a locomotive's duties are undertaken at 30 per cent or less of maximum continuous rating.

The arrangement and metallurgy of valves, pistons, and piston rings must also be taken into account, and it is not possible to " pick out of the air " any one physical factor without due consideration of the many others.

Concerning the use of free piston gasifiers, it is agreed their use for traction purposes is in an early stage of development, but it must be remembered that the power to weight ratio of a diesel engine is very different from the power to weight ratio of a diesel-powered locomotive, and it is in this latter respect that it is found the gas-generator locomotive enjoys an advantage which appears to vary between 7 and 50 per cent in comparison with the modern diesel locomotive.

F. Fancutt: We have in most of the nine Area Chemical Laboratories of the British Railways Research Department organization both staff possessing the qualifications and experience required to undertake chemical analyses and physical testing of engine oil samples, and the apparatus required for this purpose. In fact, for many years past we have examined a large number of control samples from the engines of diesel shunting locomotives.

In conjunction with departments responsible for the operation and maintenance of diesel power units, the Research Department has made arrangements in readiness to apply a complete system of control to the engines of railcars, and also to the considerable number of main-line passenger and freight locomotives which will be coming into service during the next few years.

We are fully aware of the systems of central laboratory and diesel depot control employed in America and, by reason of our representation on technical committees of the O.R.E. organization of the International Union of Railways, have an intimate knowledge of the systems in operation by Continental railways, and of the standards of used oil analysis data adopted by them for the purpose of determining optimum oil change periods, etc., for all classes of diesel engines.

The Commission has authorized the purchase of spectrographic equipment for the examination of diesel sump oils, and this will shortly be installed in one of the Area Chemical Laboratories.

The authors in reply, write: We are grateful to Mr Fancutt for his contribution as it gives due prominence in a precise manner of the full awareness by British Railways Research Department to the importance of used diesel engine oil quality control.

British Railways have not had to consider this issue on such a large scale in the past, and we wished to stimulate the thought that not only do the chemists and engineers need the appreciation of this fact in their respective spheres, but it is necessary to effect a co-ordination of each one's activities and technology with the other to a degree not experienced previously.

R. Tourret: The authors have presented an admirable summary of the lubrication requirements arising from railway traction modernization. I say " requirements " instead of " problems " deliberately, since surely the technical requirements can be met.

I have one query, and that relates to the used detergent oils and the effect of the alkalinity/acidity state of the oil on its performance. The admirable exposition of Neutralization Number in the Appendix refers to Total Acid Number only and not to Strong Acid Number. It is agreed that TAN gives no consistent relationship between acidity of the oil and engine deposits and wear. However, it has been shown,* on one engine at least, that a relationship could exist between SAN and engine deposits and wear. There is little doubt that SAN is the critical criterion. This relationship may not be obtained for other engines. Also, there may be oils of an unusual character which do not follow the relationship, although the range tested in the tests quoted was quite large. At the moment, these possibilities require exploration, and I would like to know if it has been possible to obtain any relevant data from the trials mentioned in the paper.

The authors, in reply, write: In the U.K. trials mentioned in the paper, it was not possible to obtain data relating to the influence of Strong Acid Number on deposit formation and wear. This would have meant engine examination at regular intervals, which was not practical, particularly when it is realized that in some of the trials mentioned the engines have yet to be stripped for examination, and satisfactory performance is currently based on the mileage achieved and lubricating oil analysis data.

To obtain any useful field information on this subject will require years of operation on a variety of oils, and for this reason the opportunity was taken of quoting American experience (see Table VII and p. 190, paragraphs 1 and 2). However, even here it has not been practicable to determine in the field whether it is beneficial to change an oil when strong acids appear (*i.e.* at pH 4 or below).

Limited engine test results at the authors' laboratories have indicated that, with some oils, deposits do in fact begin to form when strong acids become apparent in an

* Tourret, R., and Bale, R. W., " Influence of Acidity of the Lubricating Oil on the Wear and Deposits obtained in the Caterpillar 1A Oil Test Engine," I.Mech.E. Conference on Lubrication and Wear, Paper No. 64, October 1957.

oil. However, it is not assumed from this that with all oils in all types of engines strong acids must be prevented in order to stop deposit formation, and, as indicated in p. 190, paragraph 2, instances can be quoted where there is still effective detergency despite the presence of strong acids.

It may, however, be true to say that from the operator's point of view, where a wide variety of oils is available, it is desirable to change his oil before strong acids occur in order to provide the widest protection possible. However, whether this is a practical proposition is another matter.

ON THE BOUNDARY LUBRICITY OF NON-POLAR HYDROCARBON OILS AND THEIR MIXTURES *

By YASUKATSU TAMAI †

SUMMARY

The boundary lubricity of four different non-polar hydrocarbon oils (benzene, cetane, decalin, and di-*cyclo*-hexyl methane) and some mixtures of them was investigated by measuring simultaneously the coefficient of friction and the electrical contact resistance between steel surfaces during reciprocating sliding. The effects of oils in the solid and liquid phases were examined and varying atmospheric conditions were also studied. Wear was detectable only by the measurement of the contact resistance. It was found that the non-polar oils studied, including solid cetane, have no friction-reducing property, but have some dust-excluding and gas-shielding properties. With the exception of solid cetane they have no wear-reducing properties. It was also found that the liquid mixtures containing cetane behave like solid cetane below 17° C.

INTRODUCTION

A NUMBER of investigations have been carried out on the relation between the oiliness and the molecular structure of hydrocarbon oils. Most theoretical investigations are concerned with the oiliness in static or dynamic friction or unidirectional sliding, in which a slider runs once on the lubricated smooth surface. Hardy,[1] Bowden,[2] and others have shown that, under such experimental conditions, the long-chain normal paraffins when applied as lubricants can reduce the friction of steel and other metals; *e.g.* cetane reduces the coefficient of friction of steel from 0·5 to about 0·1. Since *normal* paraffins are non-polar and cannot adhere to the metal surface, it was of interest to investigate the friction-reducing ability of *normal* paraffins under more severe conditions of sliding, such as reciprocating and repeated rubbing.

Other investigations on the lubricity of pure hydrocarbon oils were made by Rabinowicz,[3] Burwell,[4] and others. They referred to the wear-reducing ability, showing that a chemically inert liquid can play a fairly important role in the mechanism of wear and that cetane diminishes the metallic wear in sliding. Recently it was reported that the measurement of the electrical contact resistance between the sliding metals was useful for detecting the breakdown of the surface oxide [5] and the presence of the loose oxide débris,[6] both of which are closely related to the wear process. It is, therefore, also interesting to study the wear-reducing ability of pure hydrocarbon oils by measuring the contact resistance simultaneously with the coefficient of friction.

The purpose of this work was to obtain further information about the boundary lubricity of non-polar hydrocarbon oils and their mixtures by introducing the measurement of electrical contact resistance under the condition of reciprocating and repetitive sliding. In addition, the effects of temperature and atmospheric conditions on both the friction- and wear-reducing properties were examined.

EXPERIMENTAL

(1) *Apparatus*

A pendulum-type friction apparatus[6] was used with the " crossed cylinders " arrangement of steel specimens. The pendulum swings at a maximum speed of 0·3 cm/sec.$^{-1}$, the period is 2 cycles/sec, and the average load at each contact is 100 g or 25 g. The coefficient of friction was calculated from the measured damping motion of the pendulum.

The electrical contact resistance was measured by a d.c.-potential method, and care was taken to keep the applied potential below 100 mV.

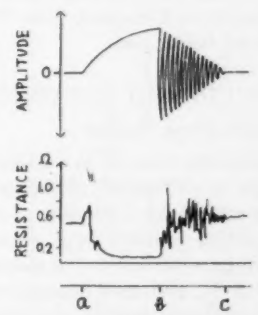

FIG 1

TYPICAL PATTERNS OF DAMPING MOTION OF FRICTION PENDULUM AND THE ELECTRICAL CONTACT RESISTANCE IN DRY FRICTION OF STEEL

The damping motion of the pendulum and the potential drop across the interface were recorded automatically, a typical pattern being shown in Fig 1.

(2) *Steel Specimens and Hydrocarbon Oils*

The cylinders were of hardened steel, and they were degreased in a boiling mixture of alcohol and KOH(5%).

* MS received 31 December 1957.

† Institute of Science and Technology, University of Tokyo.

The hydrocarbons used were benzene, decalin, di-*cyclo*hexyl methane, and cetane. As very small quantities of polar substances have a marked influence on the lubricity of oil, any such impurities were removed by first treating the oils with acid. For cetane, 5 per cent fuming sulphuric acid [7] was used and for other oils 98 per cent sulphuric acid in the acid-to-oil ratio of 1 : 1. Acid–oil mixtures were stirred vigorously for more than 10 hours and then brought into contact with active clay, washed with alkali and water, again contacted with active clay and then distilled to separate minute clay powder which could not be filtered off. The samples were then spectroscopically pure.

(3) *Measuring Procedure*

Measurements were made using the following procedure: First, the pendulum was tilted to a definite inclination, and then was set free to swing until it stopped. The intervals from a to b and from b to c in Fig 1 correspond to these two stages. Contact resistance was recorded from the start, and usually this procedure was repeated without any modification. The number of these successive measurements is represented by m.

Oil was charged to the friction contacts in two ways. In the first method the oil was charged before any measurement was made so that the steel specimens were smooth (denoted by S). In the second method the charge was made after previous measurements of dry friction, the surfaces thus being already damaged (denoted by D). To charge the oil, a platinum wire was used, one end of which was attached to a glass rod. The other end of the wire was coiled and a drop of oil was easily added to each contact from the coiled tip, which was burned before use.

RESULTS AND DISCUSSION

(1) *Dry Steel as a Blank Surface*

The steel specimens were left in a desiccator at room temperature for a prolonged period after surface-finishing. The coefficient of friction, μ, of dry steel in reciprocating sliding started from about 0·35–0·40, increased gradually with successive measurements up to 0·50 at $m = 5$–10, and then became constant.

The resistance characteristics are somewhat complicated, as shown in Fig 1. The value of the contact resistance, R, decreased steadily from $10^{-1}\ \Omega$ at a to $10^{-2}\ \Omega$ at b, showing the breakdown of surface oxide due to the unidirectional sliding. All workers agree with this point of view, and the value of $1 \times 10^{-2}\ \Omega$ indicates direct contact of the sliding surfaces, if not naked metal-to-metal contact. In this paper such a resistance is described as "zero." At b, where the pendulum was set free, R increased suddenly and then fluctuated violently throughout the interval b–c. The fluctuation of R was considered to be due to the presence of wear oxide débris between the sliding surfaces.[6] In order to represent this characteristic the original pattern of the record should be given, but the round average of fluctuating resistance, R_s, is also significant because it is a parameter of the degree of wear. At c, where the pendulum stopped, R became steady again. It is denoted by R_r and was not necessarily $10^{-2}\ \Omega$, often it was $10^{-1}\ \Omega$, and it also varied with the successive measurements. It is suggested that wear débris was not always excluded from between the contact region when the pendulum stopped.

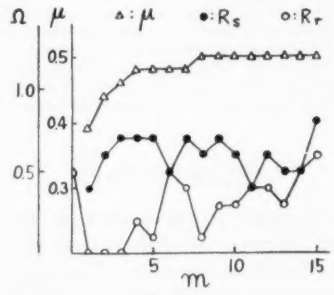

FIG 2

A TYPICAL RESULT OF THE SUCCESSIVE MEASUREMENTS OF μ, R_s, AND R_r WITH STEEL

Typical results of successive measurements on dry steel are shown in Fig 2, where μ, R_s, and R_r are plotted against m. It is readily seen that there is no relation between the values of μ and those of R_s or R_r.

(2) *Liquid Hydrocarbon Oils*

Boundary lubricity of benzene, di-*cyclo*hexyl methane, decalin, and cetane were studied with a load of 100 g and at room temperature. In Fig 3 typical

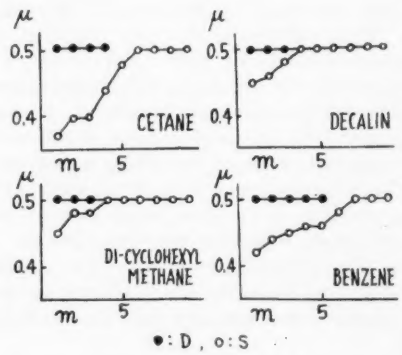

FIG 3

FRICTIONAL CHARACTER OF STEEL LUBRICATED WITH SOME LIQUID HYDROCARBON OILS

friction results are shown under conditions of S and D. The value of μ after repeated measurements became 0·50 in every case. Comparing these results with that of dry steel, it is clear that these oils have no friction-

reducing property. Murray and Johnson [8] reported that benzene and *cyclo*hexane have no oiliness, but with cetane previous workers found some oiliness, although not so effective as that of polar oils.[9] The difference between the early and the present work on cetane is probably due to different experimental conditions, *i.e.* unidirectional and reciprocating sliding.

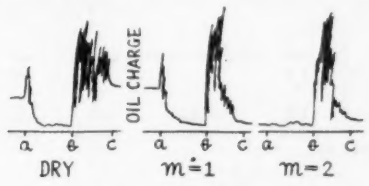

FIG 4

CHANGE IN CONTACT RESISTANCE OF SLIDING STEEL WHEN LUBRICATED WITH DECALIN

Measurements of contact resistance showed that when oil was added to the sliding contact in the *D* state, a marked change occurred in the R_r-character which, as for example shown in Fig 4 with decalin, was the lowering of R_r down to a value nearly equal to the resistance of direct contact. This change was common to cetane and di-*cyclo*hexyl methane. As R_s-character was the same as with the dry steel surface, these oils are considered to offer no surface protection. But the lowering of R_r suggests that these oils might have the ability to prevent the wear débris from adhering again to the metal surface. Burwell and Strang [4] also referred to this, but gave no direct evidence.

(3) *Cetane in Liquid and Solid States*

It is commonly accepted that *normal* paraffins in the solid state have an oiliness comparable to higher

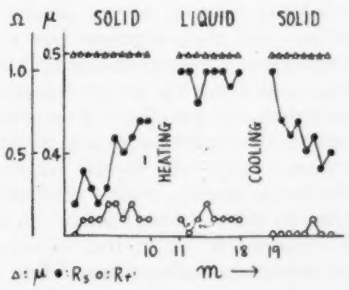

FIG 5

THE EFFECT OF PHASE CHANGE OF CETANE ON FRICTION

alcohols or fatty acids. Therefore, the lubricity of cetane could be affected by varying temperature and by the load. Some experiments were planned from this standpoint.

The effect of temperature was investigated by measuring μ, R_s, and R_r simultaneously with a load of 100 g. Temperature was varied from 40° C for liquids to 10° C for solids, and successive measurements were made from high to low temperatures continuously so as to keep other conditions unchanged, except the degree of surface damage inevitable for successive

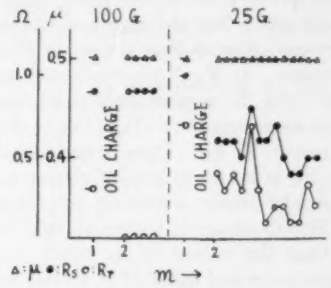

FIG 6

THE EFFECT OF LOAD ON THE LUBRICITY OF CETANE

rubbing. Typical results are shown in Fig 5, in which no change in μ and a marked change in R_s were observed with the phase change of cetane. R_s of solid cetane was considerably lower than that of the liquid, but during the swing of the friction pendulum still fluctuated as with liquid.

The effect of load was examined with liquid cetane under the condition of *D*. Loads of 100 g and 25 g were applied, and the results are shown in Fig 6.

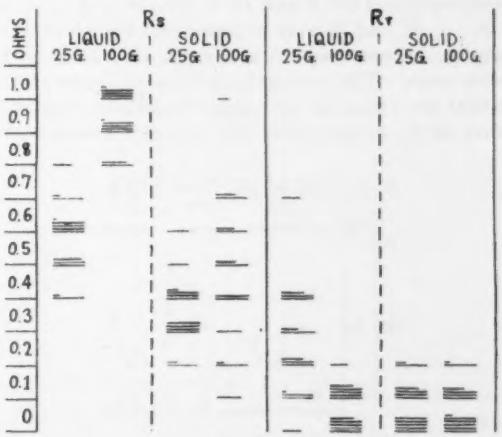

FIG 7

STATISTICAL DIAGRAM OF THE CONTACT RESISTANCE OF SLIDING STEEL LUBRICATED WITH CETANE UNDER VARIOUS CONDITIONS OF LOAD AND PHASE

A bar of full length corresponds to 10%

Here μ was constant and equal to the coefficient of dry friction of steel, 0·50, in every case, and R_s was equal to that of dry steel at the heavy load, but became lower at the light load. For R_r, the lowering tendency due to oil addition was observed at both loads, although at light load R_r was considerably higher than the resistance of direct contact.

Some other experiments were carried out under different conditions and combinations of loads, temperatures, and procedure. In all experiments μ was constant, indicating that cetane has no friction-reducing property even in the solid state under the above conditions. But the characteristics of contact resistance were influenced by the applied load and the state of cetane. In Fig 7 the statistical values of R_s and R_r for over 20 experiments are classified into four groups according to the liquid or solid states and light or heavy loads. These results indicate the following: R_s is lower with solid cetane and at light load; R_r of solid cetane is scarcely influenced by load, but R_r of liquid cetane is higher at light load. It is probable that the values of R_s relate to the wear-reducing property and those of R_r to the dust-excluding property. The higher R_r of liquid cetane at light load may be explained by the fact that the lighter load increases the probability that direct contact is prevented by wear débris.[10]

(4) *Mixed Oils*

Two oils were used, one 2 mol of cetane and 1 mol of *normal* heptane (*c–h*), and the other 3 mol of cetane and 1 mol of decalin (*c–d*). Pure cetane crystallizes at 17° C, but *c–h* and *c–d* are liquid at 11° C and 15° C respectively.

Measurements were made at the load of 25 g and temperature of 30° C and 15° C for *c–d*, and 11° C for *c–h*. μ, R_s, and R_r were recorded and Fig 8 shows the results. μ was constant and equal to 0·50 as in all other cases. The most striking feature of these results is that the values of the contact resistance, especially those of R_r, of the mixed oils at temperatures below

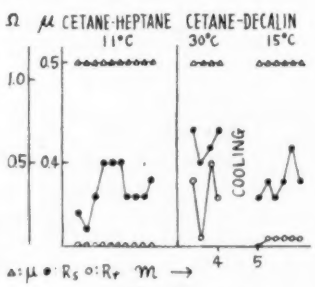

Fig 8

THE LUBRICITY OF MIXED OILS

the melting point of cetane resemble closely those of cetane in solid state. It is not easy to interpret this phenomenon, unless the liquid structure of the mixed oils is known.

(5) *Cetane in Air of* 1 *mm Hg and in Argon*

The influence of the surrounding atmosphere was also studied with liquid cetane with a load of 100 g. The measurements were made continuously under three conditions, *i.e.* air of 1 atm, air at 1 mm Hg, and argon at 1 atm. The results are shown in Fig 9. It is clear that μ was not sensitive to the atmosphere, while R_s varied markedly immediately after the change of the atmosphere. R_s decreased in the poor-oxygen atmosphere but fluctuated as before. In dry friction

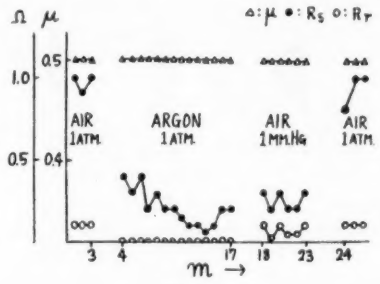

Fig 9

THE EFFECT OF SURROUNDING ATMOSPHERE ON THE LUBRICITY OF CETANE

of steel, R_s does not decrease under the evacuated condition.

The lowering of R_s probably means that wear still occurred but débris decreased in quantity and became small in size. As the load was 100 g (heavy) and the cetane was liquid, this should not be due to the wear-reducing property of cetane. Therefore, it may be mainly due to the poor content of oxygen in the atmosphere and the resistance to the diffusion of oxygen through the cetane, with the result that the reproduction of oxide film on the worn steel surface is retarded.

CONCLUSIONS

The lubricity of benzene, cetane, decalin, di-*cyclo*-hexyl methane, and their mixtures was studied by making simultaneous measurements of friction and contact resistance under the severe conditions of reciprocating sliding, and the effects of temperature and the surrounding atmosphere were also investigated.

The frictional properties depend largely on the sliding conditions, namely, static, unidirectional, or reciprocating, as well as on the load and on the speed. Non-polar hydrocarbon oils studied have no friction-reducing properties in reciprocating sliding, but they show some dust-excluding properties. The gas-shielding properties of oils are verified by the measurement of contact resistance. They have also no wear-reducing properties in liquid state.

Liquid mixtures containing cetane, at temperatures below the melting point of cetane, show some wear-reducing property, as also does solid cetane. The investigation has not yet reached the stage when this phenomenon can be explained with any degree of certainty.

ACKNOWLEDGMENTS

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A RAPID METHOD FOR THE DETERMINATION OF THE AROMATIC CONTENTS OF PETROLEUM FRACTIONS BOILING ABOVE THE KEROSINE RANGE *

By B. M. BROOK † and B. T. WHITHAM †

SUMMARY

A rapid small-scale elution chromatographic procedure was developed for the separation and determination of saturates and aromatics in olefin-free fuels and oils by selective adsorption on silica gel. A simple filter paper spotting technique was used to follow the separations, and the results obtained for a number of oils and blends were compared with those from an established chromatographic method.

INTRODUCTION

THE Fluorescent Indicator Adsorption (F.I.A.) ‡ chromatographic method for the determination of aromatics, olefins, and saturates has proved of considerable use in the analysis of gasolines and kerosines. It is also possible to utilize the technique for the isolation of the hydrocarbon type fractions [1] for further analysis by gas–liquid chromatography or mass spectroscopy, and in this way the detailed composition of lower boiling petroleum fractions may be elucidated. Attempts have been made to use the F.I.A. method for the determination of hydrocarbon types in gas oils and lubricating oils,[2] and results can be obtained by means of modified fluorescent indicators and sample dilution. However, application of this modified F.I.A. method is limited to dewaxed oils of molecular weight below 400 to 450. Another disadvantage, as far as routine analysis is concerned, is the elapsed time, which may be as much as 10 to 15 hours for the normal procedure and up to 20 hours if one wishes to recover the hydrocarbon type fractions for examination by other techniques. Thus for the separation and determination of the principal hydrocarbon types in samples above the kerosine range, elution chromatographic procedures based on selective adsorption become more suitable than the F.I.A. displacement development procedure. The simple elution method for the determination of the aromatic contents of olefin-free products, which is described in this paper, is applicable up to molecular weights of at least 650 and does not require a prior dewaxing treatment of the samples. It is accurate and takes at the most 1½ hours for duplicate determinations. Furthermore, the hydrocarbon type fractions are immediately available for examination by other techniques, such as mass spectroscopy.

EXPERIMENTAL

Standard procedures for the determination of aromatic and saturate contents of oils by elution chromatography using silica gel as an adsorbent have been described.[3] These procedures are generally somewhat time-consuming and involve the use of at least 10 to 20 grams of sample. After adsorption of the oil sample, the column containing silica gel is initially developed and eluted with a volatile non-polar solvent such as aromatic-free petroleum spirit. Refractive index of the column percolate or laborious weighing of solvent-free fractions is usually used to follow the separation of the saturates, the aromatics being recovered at a later stage by elution with a polar solvent. If the sample size, and consequently the column dimensions and amount of solvent utilized, is reduced, then the procedures can be considerably more rapid and suitable for routine purposes. A difficulty when separating small oil samples by elution chromatography is that of obtaining a simple and reliable method to detect when elution of the saturate portion of the oil has been completed. One possible method is to carry out refractive index determinations on the column percolate, but it was considered that this would be inconvenient with small columns, particularly when a number were being operated simultaneously. The procedure adopted for use was to continue the elution of the saturates until a drop of percolate, collected periodically on a filter paper at the bottom of the column, failed to leave a translucent stain when viewed against a light background after the solvent had evaporated. The aromatic and saturate contents of a number of oils and blends were determined utilizing this detection technique as follows:

A half-gram sample of oil was added to a 1 cm diameter glass column containing 20 times the sample weight of activated 100–200 mesh silica gel. Under 40° C petroleum spirit was added to the column until elution of the saturate portion, as determined by the filter paper spotting technique, was complete. The eluate was collected in a tared boiling tube and the solvent removed by evaporation to give the saturate fraction. The aromatic fraction was then eluted

* MS received 27 February 1958. † "Shell" Research Ltd. ‡ ASTM D1319–56T; IP 156/58T.

with 50 ml of ether which was likewise removed by evaporation. The two fractions were weighed and expressed as percentages of the recovered oil.

The results obtained are shown in Table I and are compared with those obtained by the established procedure.[3]

Further experiments were carried out to improve the rapidity of the determinations.

DISCUSSION

The aromatic and saturate contents determined by the rapid elution method, described in detail below, are in good agreement with those obtained by the more time-consuming standard procedures at present in use (see Table I). The saturate fractions obtained were shown to be free from aromatics by u.v. spectroscopy, but small portions of saturates are frequently separated along with the aromatics, owing to tailing. This tailing effect occurs in most adsorption chromatography but the error caused in the case of aromatic/saturate determinations is generally small. The use of a standard adsorbent/sample ratio of 20 : 1 in the rapid method described does, however, result in apparently high aromatic contents being obtained when only small amounts of aromatics are present in samples. Thus, for an oil containing 0·4 per cent aromatics an aromatic content of 1·7 per cent was determined. When greater accuracy is required in the region of low aromatic contents the adsorbent/sample ratio may be reduced by increasing the sample size.

It is important to note that the true aromatic content is not obtained when any significant amounts of oxygen, nitrogen, and sulphur compounds are present in the samples, as these are separated along with the aromatics. In these circumstances arbitrary corrections can be applied from the oxygen, nitrogen, and sulphur content of the original oil to obtain an approxi-

TABLE I

Comparison of Aromatic Contents Determined by the Established Adsorption Fractionation Method [3] and the Rapid Small-scale Adsorption Fractionation Method

Oil sample	Mean aromatic and saturate contents determined by the established analytical procedure [3]		Aromatic contents determined by the rapid small-scale method, % wt			Deviation of mean results from those by the established procedure, % wt (of sample)
	Saturates, % wt	Aromatics, % wt	Duplicate results	Mean results	Deviation from mean	
Aromatic extract	6·7	93·3	93·4	93·4	0·0	+0·1
			93·3		−0·1	
Blend of aromatic extract and pure saturates from medicinal paraffin	52·2	47·8	47·9	48·2	−0·3	+0·4
			48·4		+0·2	
	74·8	25·2	27·6	27·1	+0·5	+1·9
			26·6		−0·5	
	92·1	7·9	9·5	9·7	−0·2	+1·8
			9·8		+0·1	
Heavy lubricating oil	66·4	33·6	32·7	33·0	−0·3	−0·6
			33·2		+0·2	
Medium lubricating oil	63·0	37·0	38·9	38·8	+0·1	+1·8
			38·7		−0·1	
Transformer oil	83·5	16·5	17·2	17·7	−0·5	+1·2
			18·2		+0·5	
	83·7	16·3	17·6	18·0	−0·4	+1·7
			18·3		+0·3	
Hydrofined cat cracked gas oil	36·0	64·0	65·4	65·2	+0·2	+1·2
			65·0		−0·2	
Gas oil	62·9	37·1	39·1	39·4	−0·3	+2·3
			39·6		+0·2	

Reduction of the time required for the analysis (90 minutes) can be accomplished by recovering the saturate portion of the oil only and removing the solvent from the fractions as they are being collected. In this way duplicate determinations were carried out in 45 minutes without any loss in accuracy (Table II).

TABLE II

Comparison of Aromatic Contents Obtained by Different Procedures in the Rapid Small-scale Adsorption Fractionation Method

Oil sample	Aromatic contents determined by rapid small-scale method, % wt	Aromatic contents determined by difference with the simultaneous evaporation procedure
Medium lubricating oil	38·9, 38·7 } 38·8	37·8, 37·6 } 37·7
Transformer oil	17·6, 18·3 } 18·0	17·0, 17·8 } 17·4

mate aromatic content. However, these corrections are based on assumptions regarding the molecular weight and type of compound present and consequently may be subject to considerable error.

The elution chromatographic procedure described has been found useful for studying the changes in oil composition which occur in engines, transformers, atomic piles, and many other diverse fields. Frequently, more detailed information has been obtained by analysing the separated type fractions by mass spectroscopy and other spectroscopic techniques. When easily polymerized or oxidized substances are present the procedure has the advantage of lower contact times between the adsorbent and sample compared with the established method. In the case of waxy oils it has been necessary to use jacketed columns maintained at 60° C to avoid complications due to the separation of insoluble wax in the column. *iso*-Octane and benzene plus ethyl alcohol have been used as solvents in these circumstances.

It appears, from our experience with larger scale elution chromatographic separations of olefin containing samples above the kerosine range, that the olefins would be eluted along with the saturates under the conditions used in the rapid elution method. In view of this it may be possible to determine the aromatic contents of such samples by the procedure described.

METHOD

The Determination of the Aromatic Content of Petroleum Fractions Boiling above the Kerosine Range

(1) *Scope*

The method described is applicable to the determination of aromatic contents of high boiling olefin-free petroleum fractions which are separated into polar and non-polar constituents by their relative adsorptive affinities for activated silica gel.

(2) *Outline of Method*

The oil sample, diluted with A.R. petroleum spirit boiling below 40° C, is separated into two main fractions:

(*a*) Saturates, which consist of paraffins + naphthenes, and

(*b*) Total polar constituents, which consist of aromatics with any sulphur, oxygen, or nitrogen compounds which may be present, by percolation through, and elution from silica gel contained in a column of specified dimensions. The experimental variables such as silica gel/sample ratio, solvent volumes, etc., are standardized.

(3) *Apparatus*

(i) Two adsorption columns, being glass tubes (50 cm long by 1 cm internal diameter) drawn out into a long taper at the lower end to 2 mm i.d. and having a bulb of about 50 ml capacity at the upper end (Fig 1).

(ii) Vacuum pump fitted with a cold trap.

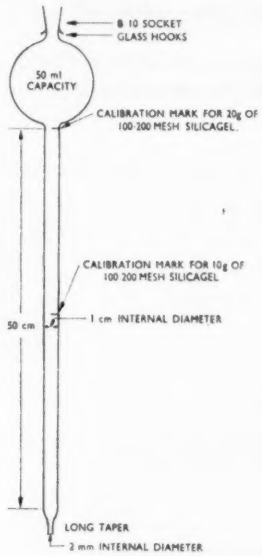
B 10 SOCKET
GLASS HOOKS
50 ml CAPACITY
CALIBRATION MARK FOR 20g OF 100-200 MESH SILICAGEL.
CALIBRATION MARK FOR 10g OF 100-200 MESH SILICAGEL
50 cm
1 cm INTERNAL DIAMETER
LONG TAPER
2 mm INTERNAL DIAMETER

FIG 1

ABSORPTION COLUMN FOR THE CHROMATOGRAPHIC DETERMINATION OF AROMATIC CONTENTS OF PETROLEUM FRACTIONS BOILING ABOVE THE KEROSINE RANGE

(iii) Graduated measuring cylinders, 4 × 25 ml capacity.

(iv) Two water or oil baths capable of being maintained at any temperature in the range of 50° to 100° C.

(v) Six numbered boiling tubes 170 mm × 25 mm.

(4) *Reagents*

(i) Silica gel 100–200 mesh activated in an oven at 160° C for 8 hours before use. (Surface area not less than 620 m^2/g by N_2 adsorption.)

(ii) A.R. petroleum spirit boiling below 40° C.

(iii) A.R. ether.

(5) *Procedure*

(*a*) Into the lower end of the clean dry glass adsorption column place a plug of cotton wool to support the adsorbent. Silica gel, taken straight from the activating oven, is added to the column, which is tapped until the level of the gel remains constant at a mark equivalent to 10 g. Place a small plug of glass wool on top of the gel and clamp the column in a vertical position. As far as possible the column should be sealed by rubber bungs during the above packing process and while the adsorbent is cooling.

(*b*) Weigh all the boiling tubes to be used in the

determination to the nearest 0·2 mg (a small piece of pumice is added to each tube prior to weighing).

(*c*) Weigh 0·5 g of sample into a 15-ml weighing bottle and dilute with 5 ml of petroleum spirit (A.R., boiling under 40° C).

(*d*) Add 10 ml of petroleum spirit to the top of the column. After the solvent has entered the silica gel, add the diluted sample and thoroughly wash out the weighing bottle with the minimum amount of solvent into the top of the column. When all the diluted sample has entered the silica gel, add further 10-ml quantities of petroleum spirit so that the column is never allowed to run dry during the development and elution stages.

(*e*) Collect the fractions from the bottom of the column in 25-ml measuring cylinders and transfer to the weighed boiling tubes containing small pieces of pumice.

(*f*) When approximately 17 ml of petroleum spirit has been collected from the column, determine the cut point between the saturates and aromatics by taking one drop of the percolate on a Whatman No. 1 filter paper and allowing the solvent to evaporate; any oil residue is visible as a translucent spot when the filter paper is held against a light background. Repeat this every 2 ml and as soon as a drop leaves no oil residue on the filter paper, the cut point is taken by quickly changing receivers. Elute the remaining oil (the aromatics) from the column with 50 ml of ether and collect as two or three portions for convenience (see Note 2).

(*g*) Remove the solvent from the fractions by evaporation on a water bath at 50° C and finally under vacuum (2 mm Hg) at 100° C (see Note 3). The aromatic portions should eventually be bulked so that a single solvent-free aromatic fraction is obtained.

(*h*) When solvent stripping has been completed and the percolated oil has been weighed, add the weights of the total aromatic and saturate fractions together to give the recovery, which should lie between 98 and 102 per cent wt of the charge. If the recovery is outside these limits the percolation should be repeated (see Note 4).

(6) *Calculation of Total Aromatics (Polar Constituents) and Saturates*

$$\text{Recovery, \% wt} = \frac{\text{Total wt of oil recovered} \times 100}{\text{wt of charge}}$$

$$\text{Aromatics (polar constituents), \% wt} = \frac{A \times 100}{\text{Total wt of oil recovered}}$$

A is the weight (in grams) of the combined aromatic fractions, or fraction.

$$\text{Saturates, \% wt} = \frac{S \times 100}{\text{Total wt of oil recovered}}$$

S is the weight (in grams) of the saturate fraction.

(7) *Correction of Aromatic Content*

For oils with high sulphur contents a correction can be applied to the adsorbed polar constituents from the sulphur content by assuming that all the sulphur compounds concentrate in this fraction, contain only one atom of sulphur per molecule, and have molecular weights the same as the original oil. When oxygen and/or nitrogen compounds are present in significant amounts similar corrections can be applied.

Precision

Repeatability. The determinations are carried out in duplicate, and results should not differ by more than ±0·5 per cent wt from the mean (see Table I).

Reproducibility. Not determined.

Note 1: A fixed adsorbent/sample ratio of 20 : 1 is used. This gives satisfactory separations of samples containing up to 95 per cent wt of aromatics. With samples containing less than about 40 per cent of aromatics there will be a tendency for the aromatic contents to be high by about 1 or 2 per cent above that determined by the normal analytical adsorption method.

Note 2: For routine determinations it is unnecessary to recover the polar constituents, as the aromatic content can be determined by difference. Also, solvent removal can be carried out simultaneously with percolation by collecting the percolate in heated tared boiling tubes.

Note 3: Owing to the volatility of samples in the gas oil range, the last traces of solvent cannot be removed from the fractions by vacuum treatment without loss of sample, and so a modified procedure is used. The boiling tubes containing the fractions are allowed to stand in ½ inch of water in a water-bath controlled at 60° C for one hour. The tubes are removed, dried and weighed, replaced in the bath for a further 10 minutes, and re-weighed. This process is repeated until the weight is constant.

Note 4: High recoveries can be caused by fines or impurities in the silica gel and washing by decantation with water and alcohol is sometimes necessary prior to activation.

ACKNOWLEDGMENTS

The authors wish to thank all those at Thornton Research Centre who took part in the work described and the directors of "Shell" Research Ltd for permission to publish this paper.

References

1 Whitham, B. T. "Vapour Phase Chromatography," ed. D. H. Desty. London: Butterworths Scientific Publications, 1957, p. 395.
2 Knight, H. S., and Greonnings, S. *Analyt. Chem.*, 1956, **18**, 1949.
3 Beaven, G. H., Foster, L. F., and Thompson, C. N. *J. Inst. Petrol.*, 1950, **36**, 89.

mate aromatic content. However, these corrections are based on assumptions regarding the molecular weight and type of compound present and consequently may be subject to considerable error.

The elution chromatographic procedure described has been found useful for studying the changes in oil composition which occur in engines, transformers, atomic piles, and many other diverse fields. Frequently, more detailed information has been obtained by analysing the separated type fractions by mass spectroscopy and other spectroscopic techniques. When easily polymerized or oxidized substances are present the procedure has the advantage of lower contact times between the adsorbent and sample compared with the established method. In the case of waxy oils it has been necessary to use jacketed columns maintained at 60° C to avoid complications due to the separation of insoluble wax in the column. *iso*-Octane and benzene plus ethyl alcohol have been used as solvents in these circumstances.

It appears, from our experience with larger scale elution chromatographic separations of olefin containing samples above the kerosine range, that the olefins would be eluted along with the saturates under the conditions used in the rapid elution method. In view of this it may be possible to determine the aromatic contents of such samples by the procedure described.

METHOD

The Determination of the Aromatic Content of Petroleum Fractions Boiling above the Kerosine Range

(1) *Scope*

The method described is applicable to the determination of aromatic contents of high boiling olefin-free petroleum fractions which are separated into polar and non-polar constituents by their relative adsorptive affinities for activated silica gel.

(2) *Outline of Method*

The oil sample, diluted with A.R. petroleum spirit boiling below 40° C, is separated into two main fractions:

(*a*) Saturates, which consist of paraffins + naphthenes, and

(*b*) Total polar constituents, which consist of aromatics with any sulphur, oxygen, or nitrogen compounds which may be present, by percolation through, and elution from silica gel contained in a column of specified dimensions. The experimental variables such as silica gel/sample ratio, solvent volumes, etc., are standardized.

(3) *Apparatus*

(i) Two adsorption columns, being glass tubes (50 cm long by 1 cm internal diameter) drawn out into a long taper at the lower end to 2 mm i.d. and having a bulb of about 50 ml capacity at the upper end (Fig 1).

(ii) Vacuum pump fitted with a cold trap.

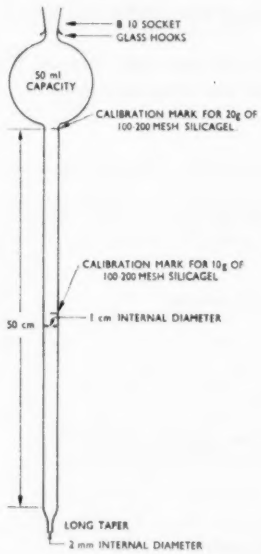
B 10 SOCKET
GLASS HOOKS
50 ml CAPACITY
CALIBRATION MARK FOR 20g OF 100-200 MESH SILICAGEL
CALIBRATION MARK FOR 10g OF 100-200 MESH SILICAGEL
50 cm
1 cm INTERNAL DIAMETER
LONG TAPER
2 mm INTERNAL DIAMETER

FIG 1

ABSORPTION COLUMN FOR THE CHROMATOGRAPHIC DETERMINATION OF AROMATIC CONTENTS OF PETROLEUM FRACTIONS BOILING ABOVE THE KEROSINE RANGE

(iii) Graduated measuring cylinders, 4 × 25 ml capacity.

(iv) Two water or oil baths capable of being maintained at any temperature in the range of 50° to 100° C.

(v) Six numbered boiling tubes 170 mm × 25 mm.

(4) *Reagents*

(i) Silica gel 100–200 mesh activated in an oven at 160° C for 8 hours before use. (Surface area not less than 620 m^2/g by N_2 adsorption.)

(ii) A.R. petroleum spirit boiling below 40° C.

(iii) A.R. ether.

(5) *Procedure*

(*a*) Into the lower end of the clean dry glass adsorption column place a plug of cotton wool to support the adsorbent. Silica gel, taken straight from the activating oven, is added to the column, which is tapped until the level of the gel remains constant at a mark equivalent to 10 g. Place a small plug of glass wool on top of the gel and clamp the column in a vertical position. As far as possible the column should be sealed by rubber bungs during the above packing process and while the adsorbent is cooling.

(*b*) Weigh all the boiling tubes to be used in the

determination to the nearest 0·2 mg (a small piece of pumice is added to each tube prior to weighing).

(*c*) Weigh 0·5 g of sample into a 15-ml weighing bottle and dilute with 5 ml of petroleum spirit (A.R., boiling under 40° C).

(*d*) Add 10 ml of petroleum spirit to the top of the column. After the solvent has entered the silica gel, add the diluted sample and thoroughly wash out the weighing bottle with the minimum amount of solvent into the top of the column. When all the diluted sample has entered the silica gel, add further 10-ml quantities of petroleum spirit so that the column is never allowed to run dry during the development and elution stages.

(*e*) Collect the fractions from the bottom of the column in 25-ml measuring cylinders and transfer to the weighed boiling tubes containing small pieces of pumice.

(*f*) When approximately 17 ml of petroleum spirit has been collected from the column, determine the cut point between the saturates and aromatics by taking one drop of the percolate on a Whatman No. 1 filter paper and allowing the solvent to evaporate; any oil residue is visible as a translucent spot when the filter paper is held against a light background. Repeat this every 2 ml and as soon as a drop leaves no oil residue on the filter paper, the cut point is taken by quickly changing receivers. Elute the remaining oil (the aromatics) from the column with 50 ml of ether and collect as two or three portions for convenience (see Note 2).

(*g*) Remove the solvent from the fractions by evaporation on a water bath at 50° C and finally under vacuum (2 mm Hg) at 100° C (see Note 3). The aromatic portions should eventually be bulked so that a single solvent-free aromatic fraction is obtained.

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Note 3: Owing to the volatility of samples in the gas oil range, the last traces of solvent cannot be removed from the fractions by vacuum treatment without loss of sample, and so a modified procedure is used. The boiling tubes containing the fractions are allowed to stand in ½ inch of water in a water-bath controlled at 60° C for one hour. The tubes are removed, dried and weighed, replaced in the bath for a further 10 minutes, and re-weighed. This process is repeated until the weight is constant.

Note 4: High recoveries can be caused by fines or impurities in the silica gel and washing by decantation with water and alcohol is sometimes necessary prior to activation.

ACKNOWLEDGMENTS

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References

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2 Knight, H. S., and Greonnings, S. *Analyt. Chem.*, 1956, **18**, 1949.
3 Beaven, G. H., Foster, L. F., and Thompson, C. N. *J. Inst. Petrol.*, 1950, **36**, 89.

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THE INSTITUTE OF PETROLEUM

ANNUAL REPORT

For the Year Ending 31 December 1957

GENERAL

The Institute's new headquarters

On 28 November the Institute's new building at No. 61 New Cavendish Street was officially opened by the Right Honourable Lord Mills, K.B.E., The Minister of Power.

The Architect, Mr R. N. Wakelin, and the builders, Richard Costain and Company Ltd, have very skilfully combined the old with the new, and the building should allow the Institute full scope for its work in the future. The Council would like to express their very grateful thanks to all those members and member companies who have so generously contributed to the Building Fund.

Honours

The Council offers its congratulations to the following members of the Institute who were honoured by Her Majesty the Queen during 1957:

C.B.E.

C. M. Crawley, F.Inst.Pet.
H. M. Jones, M.Inst.Pet.
E. J. Sturgess, F.Inst.Pet.
C. M. Vignoles, M.Inst.Pet.

M.B.E.

G. M. Davies, A.M.Inst.Pet.

General Meetings

Nine General Meetings were held during the year. Attendances were well up to average, and covered a large number of the various aspects of the science of petroleum. In addition, a special meeting was held in July, when Dr F. D. Rossini, of the Carnegie Institute, Pittsburgh, addressed members on the subject of " Hydrocarbons from Petroleum."

Annual Dinner

Sir John Maud, G.C.B., C.B.E., Permanent Secretary of the Ministry of Power, was the Guest of Honour at the Annual Dinner of the Institute, held once again at Grosvenor House in February. About 1300 members and their guests were present.

Summer Meeting

The Summer Meeting was held in June in Folkestone, the total attendance being about 140. Members and their wives spent a most enjoyable three days. The theme of the papers presented and discussed was " The Influence of Engineering on the Petroleum Industry."

Awards

On 24 October at the Royal Institution, The Right Honourable Lord Godber, of Mayfield, Chairman of the " Shell " Transport and Trading Company Ltd delivered the Fifth Cadman Memorial Lecture and received the Cadman Medal. The title of the lecture was " Oil and Education."

Lt.-Col. S. J. M. Auld, O.B.E., M.C., D.Sc., was awarded the Honorary Fellowship of the Institute, and Dr E. B. Evans, M.Sc., Ph.D., F.R.I.C., was awarded the Eastlake Medal.

Studentship

Mr R. A. Barry was awarded the Institute's Annual Prize at the Imperial College of Science and Technology, and Mr G. W. Smith the Institute's Scholarship at the University of Birmingham.

Benevolent Fund

Assistance was continued during the year for two applicants.

Branches

A very successful year was reported from all Branches.

A very popular and well organized Children's Lecture was held in Swansea by the South Wales Branch, in conjunction with University College, Swansea. Mr J. R. Joyce, of the Thornton Research Centre of " Shell " Research Ltd, was the lecturer.

By-Laws

The changes in the Institute's Constitution, foreshadowed in the By-Laws Committee's report for 1956, were dealt with during 1957, in consultation with the Institute's legal advisers. The recommendations finally made to and accepted by Council

were principally connected with changes in the Memorandum of Association, which would, it was hoped, bring the Institute within the scope of the Scientific Societies Act of 1843.

The alterations were to be put before members at a Special General Meeting early in 1958.

Apart from amendments of a minor nature to the Articles of Association and By-Laws, mainly consequential on the alterations to the Memorandum, the important step of authorizing proxy voting at meetings of the Institute at which any Special Resolutions are to be put was also included in the abovementioned alterations.

At the end of the year the committee was asked to consider further amendments to the Articles and By-Laws in connexion with possible changes in the composition of the Council of the Institute.

Economics and Operations Group

The Group held seven meetings during the year the subjects being " Oil, Money, and The Public," " Do Films Serve the Oil Industry Public Relations?," " Control of Stock Losses," " Expansion in the World Oil Industry," " Some Aspects of the Economics of Tanker Design," " Relations between the Oil Industry and the Automobile Industry," and " Oil Prices in 1957."

Education

The directions in which the Institute could help in the education field at various levels have been reviewed, including:

(*a*) courses for technicians and plant operators;
(*b*) courses in petroleum technology;
(*c*) University post-graduate courses in special subjects.

With regard to (*a*), special consideration has been given to the City & Guilds courses and meetings held with the City & Guilds Committee responsible for courses 7 and 24. It is expected that adjustments will be made to these courses which will increase their value to the oil industry. As far as (*b*) and (*c*) are concerned, information is being obtained and collated.

Engineering

The fourth of the series of IP Safety Codes, that for Drilling and Production, was published during the latter part of 1957, and for a Code with a limited field of application in Britain has been relatively well received.

Council decided that in addition to the existing Safety Codes, that is to say the Electrical Code and those for Marketing, Refining, and Drilling and Production, there was sufficient demand to justify the preparation of two further Codes, first, for Tankers and, secondly, for Aviation Fuelling Facilities.

The work of drafting these Codes was delegated to two new Sub-Committees, and at the end of 1957 progress was such that publication might be expected in 1958.

In electrical matters the Sub-Committee concerned has done a great deal of work in preparing further revisions to the existing Code in order to keep it up to date both with technical design and with research and developments. The result of its work should also be in print during 1958.

The Safety Sub-Committee has had several routine meetings with the object of the interchange of ideas, but fortunately has not had to consider or report on any major catastrophies.

The Committee has continued to deal with technical correspondence and queries, both on a domestic basis and from authorities in such remote places as Melbourne, Mombasa, and Port Elizabeth. It is evident that the Institute is widely accepted as a source of informed opinion in the sphere of petroleum in all its aspects. This is also indicated by the sale of Safety Codes, which up to 31 December 1957 were as follows:

Drilling and Production	422
Refining	963
Marketing	1343
Electrical (the Reprint only)	1587

Publications

Volume 43 of the *Journal* and Volume 11 of the *IP Review* were completed during 1957 with the usual twelve monthly issues. In general, they followed the same lines as the previous volumes, but it is again gratifying to record a considerable increase in the circulation, indicating the continued recognition of these publications in the field of petroleum literature.

Two book publications were produced during the year. The first of these was entitled " Engineering Progress and the Oil Industry," which included the papers read at the 1957 Summer Meeting, together with the full discussions which followed. The second publication was Part IV of the Model Code of Safety Practice in the Petroleum Industry. This Code, the " Drilling and Production Safety Code," makes recommendations regarding safe practices right through from the time the site for a well is selected up to and including the production stage.

The value of the " ASTM/IP Petroleum Measurement Tables " has been such that 1957 saw a demand for reprinting of the British and Metric volumes. In both of these the opportunity was taken to amend the remarkably few errors found in the first printing.

The year also saw work commenced on the production of new editions of two existing IP publications. These are " A Glossary of Petroleum Terms " and " Significance of Properties of Petroleum Products."

Library

The Library Sub-Committee was again able to report to the Publications Committee that there had been a considerable increase in the use made of the

Institute's library. The library is becoming more and more recognized as an important centre for information concerning the technical and scientific aspects of the petroleum industry. Improved facilities are available in the new building, including the provision of a reading-room for members.

Research

The co-operation with the Medical Research Council on biological activity of petroleum fractions has continued during the year. The Hydrocarbon Research Group has continued to support research work at various Universities and technical colleges.

Standardization

The 17th edition of " Standard Methods " was due for publication in February 1958; five new methods are included, and revisions of a technical nature have been made to twenty-seven others.

Active co-operation with the B.S.I., and with standardizing bodies in other countries concerned with methods of testing petroleum products, has continued.

The Gases and Light Distillates Sub-Committee has been re-organized, and an Analysis Sub-Committee and certain new panels are being formed, in order to keep in line with modern trends in testing methods. The arrangements for distribution of engine test correlation samples are being revised to facilitate participation by standardizing bodies in other European countries.

Staff

This year has made particularly heavy demands on the staff culminating in the move from Manson House to 61 New Cavendish Street in December.

Council has placed on record its appreciation of the special services rendered by members of the staff in connexion with the move and also of the work of the staff generally in maintaining the high standards which have come to be associated with the work of the permanent staff of the Institute.

MEMBERSHIP

Details of Membership as at 31 December 1957:

	Total 31 Dec. 1956	Changes during 1957						Total 31 Dec. 1957
		New	Trans. ferred to	Resigned	Deceased	Trans- ferred from	+ or −	
Honorary Members	2	—	—	—	—	—	—	2
Honorary Fellows	5	—	1	—	—	—	+ 1	6
Members	625	48	6	20	5	5	+ 24	649
Fellows	713	43	16	8	6	3	+ 42	755
Associate Members	843	49	2	34	6	8	+ 3	846
Associate Fellows	1245	186	5	43	4	7	+137	1382
Students	75	8	—	30	—	7	− 29	46
Totals	3508	334	30	135	21	30	+178	3686
Member Companies	189	49		2			+ 47	236

DEATHS

It is with regret that the following deaths during 1957 are recorded:

E. W. Bradbury (AM)
J. N. Cock (M)
C. Dabell (F)
R. David (AF)
W. G. W. Duncan (AF)
Dr T. K. Hanson (F)
B. Hayward (AF)
B. R. Jackson (F)
A. W. Jeffery (AF)
J. E. Jenkin (F)
R. M. Johnson (AM)
G. McPherson (AM)
R. T. Manning (AF)
The Hon. G. L. Parsons (M)
A. T. Peterson (M)
A. E. Price (M)
A. H. Ricketts (M)
N. D. Roughsedge (AM)
R. L. Sarjeant (F)
H. Stillman (AM)
Prof. J. R. H. Whiston (F)

Charles Dabell was one of those who agreed to become a member of the Institute prior to its foundation in 1914. Other members of long standing who passed away during the year were The Honourable G. L. Parsons and J. E. Jenkin, both of whom joined in 1924, B. R. Jackson, who joined in 1927, J. N. Cock, who joined in 1935, and R. David, who joined in 1936. Although R. T. Manning had been a member only since 1956, his enthusiasm was such that he was chosen as secretary of the Bahrain Branch only a short time after his election. R. L. Sarjeant was also an active participant in the work of the IP, and at the time of his death was chairman of the Marketing Sub-Committee and of the Aviation Facilities Sub-Committee of the Engineering Committee.

By Order of the Council,

C. CHILVERS,
Honorary Secretary

March 1958

BALANCE SHEET AND ACCOUNTS

VOLUME 44, NUMBER 415—JULY 1958

THE INSTITUTE

(A Company limited by Guarantee

BALANCE SHEET AS

1956 £	£		£	s.	d.	£	s.	d.
		Capital of the Institute under Bye-Laws 36, 44, and 45:						
		Life Membership Fund—	£	s.	d.			
		As at 31 December 1956	1,104	3	0			
		Add Receipts during 1957	—	—	—			
	1,104					1,104	3	0
		Entrance and Transfer Fees—						
		As at 31 December 1956	8,087	15	9			
		Add Receipts during 1957:						
		Entrance Fees	420	0	0			
		Transfer Fees	17	17	0			
	8,088					8,525	12	9
		Donations—						
	326	As at 31 December 1956				326	5	0
	9,518					9,956	0	9
	291	*Less* Net Loss on Sale of Investments brought forward				291	9	9
9,227								9,664 11 0
		Building Fund Account						
		Balance at 31 December 1956				30,449	5	5
		Add:						
		Donations Received during year				57,535	4	0
		Interest Received (Gross) during year				2,475	14	8
30,449								90,460 4 1
5		**T. C. J. Burgess Prize Fund**						5 0 0
1,702		**General Reserve (previously War Contingencies Reserve)**						1,702 0 11
		Revenue Account:						
		As at 31 December 1956				39,480	11	0
		Add Surplus for year				7,989	9	5
39,481								47,470 0 5
		Subscriptions Received in Advance:						
		Members' Subscriptions for 1958				437	12	6
		Members' Subscriptions for 1959				15	9	0
		Members' Subscriptions for 1960				4	4	0
		Member Companies' Subscriptions for 1958				140	15	0
		Journal Subscriptions for 1958				2,271	10	11
		Journal Subscriptions for 1959				68	8	9
		Journal Subscriptions for 1960				13	0	0
2,555								2,951 0 2
		Current Liabilities and Provisions:						
	350	Provision for Pension				350	0	0
	5,449	Sundry Creditors and Accrued Charges				5,214	11	6
	559	World Petroleum Congress				439	5	10
		Entertainment Account—						
		As at 31 December 1956	366	11	0			
		Less Excess of Expenditure over Receipts during year to date	31	2	4			
	366					335	8	8
6,724								6,339 6 0
		Sum Set Aside for Grants to Branches and Students' Section—unallocated:						
		Balance as at 31 December 1956				74	3	0
		Add Amount set aside during year				650	0	0
						724	3	0
		Less Grants made during year				660	0	0
74								64 3 0
£90,217								£158,656 5 7

AUDITORS' REPORT TO THE MEMBERS

We have examined the above Balance Sheet and annexed Revenue Account and report that we have obtained all the
In our opinion, proper books of account have been kept by the Institute, so far as appears from our examination of those
best of our information and according to the explanations given to us, the accounts give the information required by the
affairs at 31 December 1957, and the Revenue Account gives a true and fair view of the revenue for the year ended on that

SCOTTISH UNION HOUSE,
25 BUCKLERSBURY,
LONDON, E.C.4.
6 *March* 1958.

OF PETROLEUM

and not having a Share Capital)

AT 31 DECEMBER 1957

1956 £	£		£	s.	d.	£	s.	d.
		Leasehold Premises:						
	19,998	Cost of acquisition	19,998	10	0			
	10,467	*Add* Cost of conversion to date	57,982	7	6			
30,465						77,980	17	6
		Office and Library Furniture:						
		At valuation, being Net Amount standing in the Company's books at 1 July 1948, *less* Sales	221	10	8			
		At cost	2,793	15	8			
			3,015	6	4			
		Less Aggregate Depreciation	1,500	15	8			
1,668						1,514	10	8
		Furniture and Fittings of New Premises:						
		At cost				3,944	2	9
		Current Assets:						
	4,706	Stock of Publications as certified by the General Secretary	5,892	0	3			
	322	Stock of Envelopes (for dispatch of *Journals*)	—	—	—			
	5,841	Sundry Debtors and Payments in Advance including Income Tax recoverable	6,951	12	4			
	—	Members' subscriptions in arrear—not valued	—	—	—			
	250	Member Company's subscription in arrear	1,000	0	0			
	—	Loan—St Pancras Borough Council	25,000	0	0			
	418	Cash on Deposit with Post Office Savings Bank	428	9	9			
		Cash at Bank—	£	s.	d.			
	18,403	Deposit Account	3,000	0	0			
	7,196	Current Account	3,108	19	8			
	366	Entertainment Account	335	8	8			
			6,444	8	4			
	600	Cash in Hand	600	0	0			
38,102						46,316	10	8
		Assets Held on Account of the Building Fund:						
	18,000	Loan—St Pancras Borough Council	25,000	0	0			
	1,650	Cash at Bank on Current Account	2,065	1	4			
	—	Cash at Bank on Deposit Account	920	0	0			
	119	Interest Receivable	166	8	9			
	213	Income Tax Recoverable	748	13	11			
19,982						28,900	4	0
£90,217						£158,656	5	7

OF THE INSTITUTE OF PETROLEUM

information and explanations which to the best of our knowledge and belief were necessary for the purposes of our audit. books. The Balance Sheet and Revenue Account are in agreement with the books of account. In our opinion, and to the Companies Act, 1948, in the manner required, and the Balance Sheet gives a true and fair view of the state of the Institute's date.

SMITH & WILLIAMSON,
Chartered Accountants.
Auditors.

THE INSTITUTE

(A Company limited by Guarantee

REVENUE ACCOUNT FOR THE

1956 £	£		£ s. d.	£ s. d.
		To **Administrative Expenses:**		
12,305		Staff Salaries and National Insurance	13,559 11 10	
1,212		Staff Pension Scheme Contributions	1,203 18 9	
13,517			14,763 10 7	
7,134		*Less* Applicable to Publications	7,529 3 9	
6,383				7,234 6 10
1,607		Printing and Stationery	1,640 11 10	
1,083		General Postages	1,276 1 7	
362		Telephones, Cables, and Travelling Expenses	348 5 2	
3,052			3,264 18 7	
1,017		*Less* Applicable to Publications—one-third	1,088 6 2	
2,035				2,176 12 5
94		Audit Fee	94 10 0	
199		General Expenses	205 2 4	
67		Insurance	91 5 6	
360				390 17 10
8,778				9,801 17 1
		„ **Establishment Expenses:**		
2,942		Rent	2,952 15 5	
578		Cleaning, Lighting, and Heating	682 16 11	
33		Repairs and Maintenance	18 11 10	
3,553			3,654 4 2	
777		*Less* Applicable to Publications	803 11 0	
2,776				2,850 13 2
		„ **Meetings:**		
436		Hire of Hall, Pre-prints, Reporting, etc.		507 3 8
650		„ **Sum Set Aside for Grants to Branches and Students' Section**		650 0 0
131		„ **Miscellaneous Expenses in Connexion with the Building Fund**		— — —
		„ **Sundries:**		
268		Library Expenses	246 14 4	
11		Legal Expenses	— — —	
—		Removal Expenses	303 17 6	
81		Subscriptions to Societies	90 5 8	
100		Scholarship Awards	100 0 0	
185		Depreciation of Furniture (10%)	168 4 0	
645				909 1 6
		„ **Publications Revenue Account:**		
575		Deficit for year		1,487 15 9
6,819		„ **Balance, being Surplus Revenue for Year**		7,989 9 5
£20,810				£24,196 0 7

OF PETROLEUM

and not having a Share Capital)

YEAR ENDED 31 DECEMBER 1957

1956 £		£	s.	d.
11,249	By Members' Subscriptions received for 1957	11,917	16	0
117	,, Members' Subscriptions in arrear, received during year	257	8	0
8,725	,, Member-Company Subscriptions received for 1957	10,618	19	6
20	,, Special Subscription	20	0	0
699	,, Interest Received (Gross)	1,381	17	1
£20,810		£24,196	0	7

PUBLICATIONS REVENUE ACCOUNT FOR THE YEAR ENDED 31 DECEMBER 1957

	£	s.	d.
To Stock in Hand at 1 January 1957	4,705	16	3
,, Dispatch Expenses	1,888	15	6
,, Standard Methods (16th Edition)	1,864	10	0
,, Journal	8,877	13	5
,, IP Review	9,006	16	7
,, Binders	254	0	0
,, Drilling Code	241	3	7
,, Glossary	49	4	0
,, Handy Tables	8	17	6
,, Influence of Engineering Progress on the Oil Industry	656	3	3
,, Modern Petroleum Technology (Vol. 2)	77	4	0
,, Tables for Measurement of Oil (British)	372	12	1
,, Tables for Measurement of Oil (Metric)	416	11	8
,, Other Publications	44	14	9
,, Abstracts	680	5	7
,, Publicity	242	8	3
,, Salaries, National Insurance, and Pension Scheme Contributions	7,529	3	9
,, Proportion of Administrative Expenses	1,088	6	2
,, Proportion of Establishment Expenses	803	11	0
	£38,807	17	4

	£	s.	d.
By Advertising	16,542	14	10
,, Standard Methods (16th Edition)	5,092	3	4
,, Journal	4,714	7	11
,, Glossary	24	0	0
,, IP Review	631	8	7
,, Review of Petroleum Technology	228	0	0
,, Petroleum Measurement Manual	182	4	0
,, Handy Tables	333	9	3
,, IP Engine Test Methods for Rating Fuels	166	0	0
,, Marketing Code	196	10	6
,, Electrical Code	563	0	0
,, Drilling Code	266	16	0
,, Refining Code	189	14	6
,, Tables for Measurement of Oil (British Edition)	484	9	0
,, Tables for Measurement of Oil (Metric Edition)	287	18	10
,, Essential Factors in the Future Development of the Oil Industry	308	17	0
,, Binders	178	5	0
,, Influence of Engineering Progress on the Oil Industry	139	15	0
,, Modern Petroleum Technology (Vol. 2)	544	0	0
,, Other Publications	354	7	7
,, Stock in Hand at 31 December 1957	5,892	0	3
	37,320	1	7
,, Balance, being Deficit for year carried to Revenue Account	1,487	15	9
	£38,807	17	4

HYDROCARBON RESEARCH GROUP

Revenue Account for the Year ended 30 September 1957

	£	s.	d.	£	s.	d.
To Stock in Hand of "Applied Mass Spectrometry"				379	1	0
,, Grants:						
King's College	1,600	0	0			
University of Oxford	1,150	0	0			
University of Birmingham	400	0	0			
University of Bristol	1,000	0	0			
Queen Mary College	1,750	0	0			
University of Cambridge	600	0	0			
Imperial College of Science and Technology	700	0	0			
University of Edinburgh	350	0	0			
				7,550	0	0
,, Honoraria				420	0	0
,, General Expenses				49	0	0
,, Salaries				350	0	0
,, Expenses re Chromatography Symposium				75	0	0
				£8,823	1	0

	£	s.	d.
By Voluntary Contributions from Members of the Group	7,000	0	0
,, Sales of "Applied Mass Spectrometry"	414	9	0
,, Sales of "Molecular Spectroscopy"	2	0	0
,, Sale of Technical Reports	28	16	8
,, Stock in Hand of "Molecular Spectroscopy"	168	0	0
,, Balance, being Deficit for year	1,209	15	4
	£8,823	1	0

Notes:

(i) For convenience in administration, the Accounts of the Group are closed as at 30 September each year.

(ii) The Group are now liable to bear all losses incurred in connexion with their publications.

Statement of Funds at 30 September 1957

	£ s. d.	£ s. d.		£ s. d.
Revenue Account:			**Stock in Hand of "Molecular Spectroscopy"**	168 0 0
As at 30 September 1956	2,221 4 3		**Sundry Debtor**—The Institute of Petroleum	172 17 0
Less Deficit for year	1,209 15 4		**Cash at Bank on Current Account**	670 11 11
		1,011 8 11		
		£1,011 8 11		£1,011 8 11

We have examined the above Revenue Account and Statement of Funds with the books and vouchers of the Group and find them to be in accordance therewith.

Scottish Union House,
25 Bucklersbury,
London, E.C.4.
6 *March* 1958.

Smith & Williamson,
Chartered Accountants.
Auditors.

CARCINOGENICITY RESEARCH FUND

Statement of Funds as at 31 December 1957

	£ s. d.	£ s. d.		£ s. d.
Balance of Sum Received from the Petroleum Board (during 1947):			**Cash at Bank on Current Account**	304 0 8
As at 1 January 1957	302 17 0			
Accumulated Net Income:				
As at 1 January 1957	1 3 8			
		£304 0 8		£304 0 8

We have examined the above Statement of Funds with the books and vouchers of the Fund and find it to be in accordance therewith.

Scottish Union House
25 Bucklersbury,
London, E.C.4.
6 *March* 1958.

Smith & Williamson,
Chartered Accountants.
Auditors.

CADMAN MEMORIAL FUND

Income and Expenditure Account for the Year ended 31 December 1957

	£ s. d.	£ s. d.		£ s. d.	£ s. d.
To **Balance at 31 December 1957:**			By **Balance at 31 December 1956**	3,497 16 2	
Cash at Bank on Deposit Account	500 0 0		*Add* Interest Received (Gross)	99 19 8	
Cash at Bank on Current Account	37 8 8			3,597 15 10	
£2,730 3% Savings Bonds 1965/75 (Market Value—£1,925)	2,730 0 0	3,267 8 8	*Deduct* Cost of 5th Cadman Lecture and Memorial Dinner	330 7 2	3,267 8 8
		£3,267 8 8			£3,267 8 8

We have examined the above Income and Expenditure Account with the books and vouchers of the Fund and find it to be in accordance therewith.

SCOTTISH UNION HOUSE,
25 BUCKLERSBURY,
LONDON, E.C.4.
6 *March* 1958.

SMITH & WILLIAMSON,
Chartered Accountants.
Auditors.

BENEVOLENT FUND

Income and Expenditure Account for the Year ended 31 December 1957

1956 £		£ s. d.	£ s. d.	*1956* £		£ s. d.
105	To **Grants Paid**		110 0 0	*3,421*	By **Balance at 31 December 1956**	3,608 10 2
	„ **Balance at 31 December 1957:**			*205*	„ **Subscriptions and Donations received during year**	182 15 6
	Represented by—			*88*	„ **Interest Received (Gross)**	102 0 0
	£1,450 4½% Defence Bonds (Conversion Issue) 1,450 0 0			—	„ **Premium on Redemption of Defence Bonds**	14 10 0
	£300 3½% Defence Bonds (Conversion Issue) 300 0 0					
	£200 3½% Defence Bonds (2nd Conversion Issue) 200 0 0					
	£100 2½% Defence Bonds (Conversion Issue) 100 0 0					
	(Market Value of Investments—£2,050)	2,050 0 0				
	Sundry Debtor	5 17 0				
	Cash at Bank on Deposit Account	900 0 0				
	Cash at Bank on Current Account	841 18 8				
3,609			3,797 15 8			
£3,714			£3,907 15 8	*£3,714*		£3,907 15 8

We have examined the above Income and Expenditure Account with the books and vouchers of the Fund and find it to be in accordance therewith.

SCOTTISH UNION HOUSE,
25 BUCKLERSBURY,
LONDON, E.C.4.
6 *March* 1958.

SMITH & WILLIAMSON,
Chartered Accountants.
Auditors.

THE INSTITUTE OF PETROLEUM

FORTY-FIFTH ANNUAL GENERAL MEETING

THE Forty-fifth Annual General Meeting of The Institute of Petroleum was held at 61 New Cavendish Street, London, W.1, on 22 April 1958, the chair being taken by the President, The Rt Hon. Lord Geddes, C.B.E.

The notice convening the meeting and the minutes of the Forty-fourth Annual General Meeting and of the Special General Meeting held on 22 January 1958 were read. The minutes were confirmed and signed as a correct record.

ELECTION OF OFFICERS FOR THE SESSION 1958–59

President

The President announced that the Council had nominated C. M. Vignoles, C.B.E., managing director of Shell-Mex and B.P. Ltd. as president for the ensuing year. He said that he felt sure that every member of the Institute would feel that the Institute had been honoured by the willingness of Mr Vignoles to accept the office of president.

The proposition was seconded by C. Chilvers and carried by acclamation.

Vice-Presidents

W. S. Ault, Professor Frank Morton, and J. S. Parker, having been nominated by the Council as vice-presidents for a period of three years, it was proposed by the President and seconded by Col. T. M. Simmonds that they be so elected. This was accepted without dissent.

Members of Council

As the result of the ballot for members of Council for a term of three years the following were declared elected: V. Biske, W. M. Catchpole, E. J. Dunstan, E. B. Evans, F. L. Garton, A. J. Goodfellow, A. C. Hartley, E. C. Masterson, T. W. Mathias, C. S. Newey, E. J. Sturgess, W. H. Thomas.

Honorary Treasurer

On the motion of E. J. Sturgess, seconded by C. V. Hill, G. H. Coxon was unanimously elected as Honorary Treasurer for the session 1958–59.

Honorary Secretary

R. B. Southall proposed and R. F. Leach seconded that C. Chilvers be elected as Honorary Secretary for 1958–59. This was carried unanimously.

Ex-officio Members of Council

Nominated by Council, the following were unanimously elected as ex-officio members of Council for 1958–59: A. S. Brooman, J. R. Moore, W. M. Stirling, L. S. Thornes, D. H. Tullis, J. C. Wood-Mallock.

The motion was proposed by F. L. Garton and seconded by E. L. Sturgess.

MEMBERS ELECTED OR TRANSFERRED

In conformity with the By-Laws, a list of all persons elected or transferred during the year 1957 was tabled.

REPORT OF COUNCIL

Presenting the Report of Council for the year 1957, **C. Chilvers,** the Honorary Secretary, said that 1957 had been a year of steady progress; membership had increased by 178 as compared with an increase of 140 in 1956, and member-companies by 47 as compared with 5.

The Institute was now in its new building, which was officially opened by Lord Mills on 28 November, and thanks were due to all those members and member-companies who made it possible to have that building.

The Summer Meeting was one of the main events in the IP calendar, and the 1957 meeting continued the series of great successes of the last three or four years. Mention should be made of the Cadman Lecture given by Lord Godber when he was awarded the Cadman Medal and also that Col. S. J. M. Auld was awarded the honorary fellowship and Dr E. B. Evans the Eastlake Medal.

The Engineering Committee's safety codes were undoubtedly among the successful publications of the Institute. The fourth in the series, the Drilling and Production Code, had now been issued and two futher codes were being prepared, one for tankers and the second for aviation fuelling facilities.

Publications and Standardization were really the backbone of the Institute's activities. Last year volume 43 of the *Journal* was completed, and it maintained the high standard which the editor had set in the past. Similarly, the *IP Review* had also been very successful. Referring to the improved facilities for the Library, Mr Chilvers said he hoped that members would take full advantage of them. The revision of " Standard Methods " continued, and this opportunity should be taken of expressing appreciation of

the services rendered by those whose combined efforts were responsible for the high repute of the IP standards.

He also desired to once again express the appreciation of Council for the services which were rendered by the permanent staff.

Mr Chilvers then moved the adoption of the Report, which was seconded by J. C. Wood-Mallock.

E. M. Benjamin referred to the fall in the number of Student Members. The President said that note had been taken of this and steps were being taken to encourage students to join the Institute.

The Report was then adopted without dissent.

ACCOUNTS

G. H. Coxon, Honorary Treasurer, presenting the accounts for the year 1957, said that the principal item in the balance sheet was the expenditure on the building. The purchase of this building and the rehabilitation of it had been no mean task for the Institute, and thanks were due to the Finance Committee for building up a reserve fund. They were also grateful for the help given by the various companies. The lease of the premises cost about £20,000 and the cost of conversion up to date was £57,000. There was still about £3000 or £4000 to be paid. It must now be the policy of the Finance Committee to build the reserves up again to be ready for any further action that the Institute may in their wisdom deem advisable.

The adoption of the accounts was seconded by A. C. Hartley and carried unanimously.

AUDITORS

G. H. Coxon proposed and F. L. Garton seconded that Messrs Smith and Williamson be appointed auditors at the remuneration to be agreed by Council. This was approved unanimously.

AMENDMENT TO ARTICLES OF ASSOCIATION AND BY-LAWS

The President submitted that the three resolutions as printed in the Agenda for the meeting be passed.

D. Morgan raised a point regarding the representatives of the Branches Committee and, after this had been dealt with, the proposal was seconded by E. LeQ Herbert. The resolutions were then carried unanimously.

INDUCTION OF NEW PRESIDENT

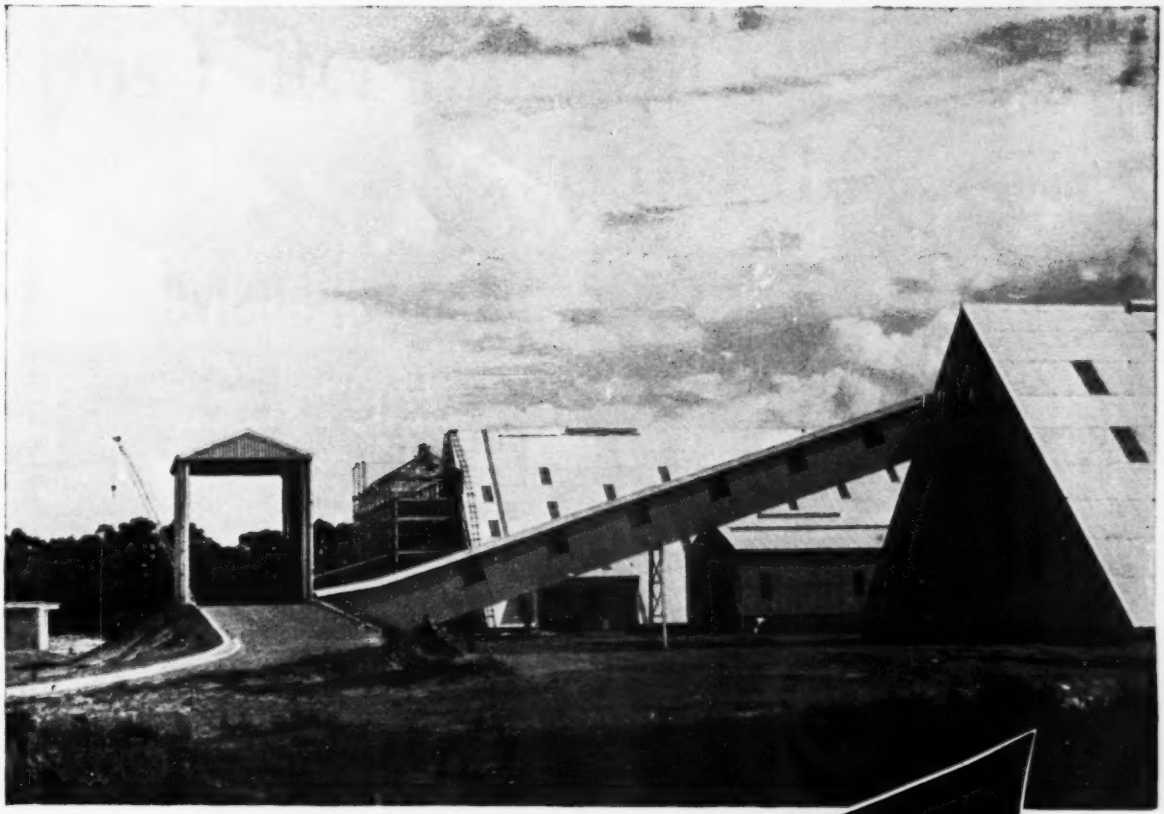
Lord Geddes, before handing over the chair to Mr Vignoles, said he would like to look back over the past two years. The Institute certainly had flourished in membership and its finances were better than they had ever been before. It had moved into its new building, and great thanks were due to Sir Stephen Gibson for the mass of work that he had undertaken as chairman of the Building Committee.

He said that he had been invited last winter to visit the Middle East Branches, and would like once more to express his thanks for the opportunity of doing so and, secondly, to say what a splendid organization the Institute had throughout the Middle East. It was something to be very proud of.

Finally, Lord Geddes said he would like to personally thank, first, the Council for the unfailing support he had had over the past two years; secondly, the members; and thirdly, the General Secretary and the staff, all of whom really are doing an excellent job on behalf of the Institute.

The chair was then taken by C. M. Vignoles, who said that he was grateful for the honour of being asked to be president of the Institute. It was a particularly formidable task. The Institute had a great part to play and his services were at its disposal, and he hoped that it would continue to be successful.

C. Chilvers, the Honorary Secretary, said they would wish to express formally their appreciation to Lord Geddes for the services he had rendered during his two years of office. Those who had been concerned with the administrative affairs of the Institute knew how well he had carried out those duties. These last two years would go down in the records of the Institute as seeing the fruition of two very important projects in its history. First, the completion of the acquisition of the new building, and secondly, the start of a new era for the Institute in that it now went forward under a revised constitution.



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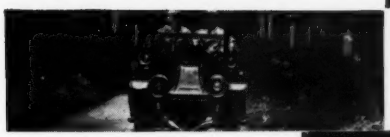
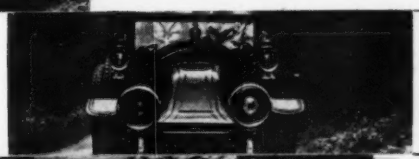
this Filter talk will drive me round the bend!

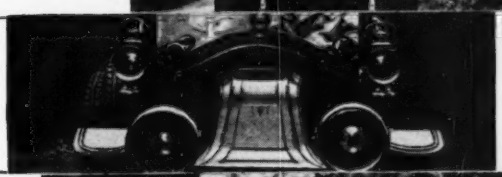
Sorry, old fruit. I was only trying to be helpful.



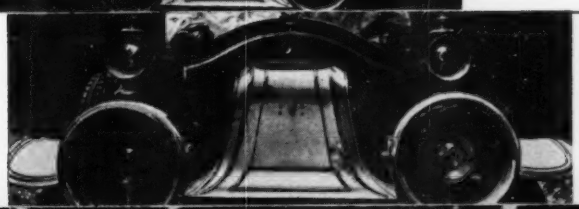
Helpful! Here am I practising for the only real sporting event of the year and all you can talk about is some wretched little gadget on one of your blasted hairyplanes. Can't you see I need to concentrate?



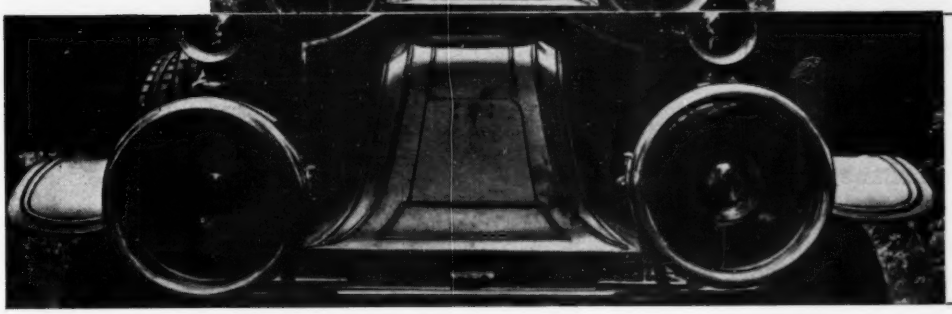
It's not a little gadget and they'd never put it on a plane—it's bigger than this Renault. They put it in the line between the storage and aircraft tanks to make sure the plane gets clean, water-free fuel.



That's the trouble with your infantile modern engines—they have to be fed on strained foods or they get indigestion. Now look at Dotty . . .



Exactly. Do you really think she enjoys having that steam pouring through her exhaust? Now if you took a Simmonds Fram Separator Filter in tow you could have 100% water separation and complete filtration of solids down to 5 microns.



It's tempting, very tempting . . . but it wouldn't be fair on the other competitors. Now d'you mind if we stop a minute . . . I think I really will have to get the rest of that bird's nest out of the tank.

the point of the argument... **FRAM SEPARATOR FILTERS** for clean water-free fuel

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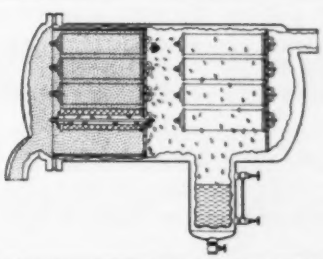

CRC 6W3

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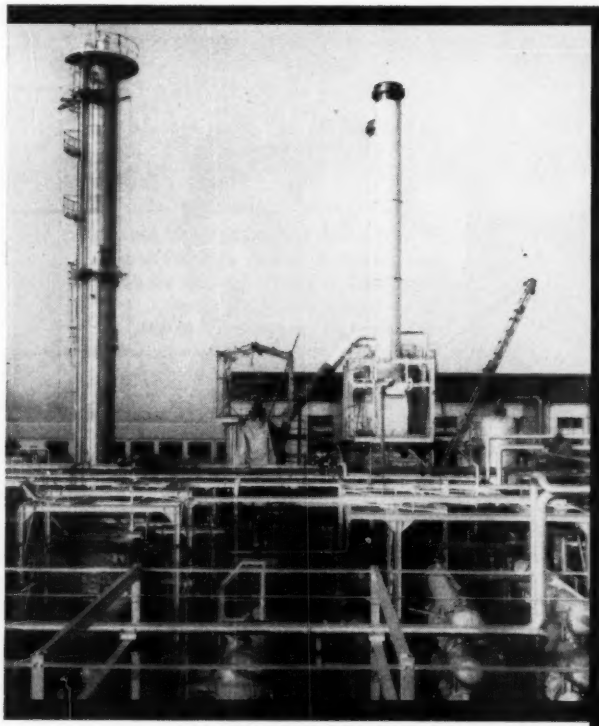
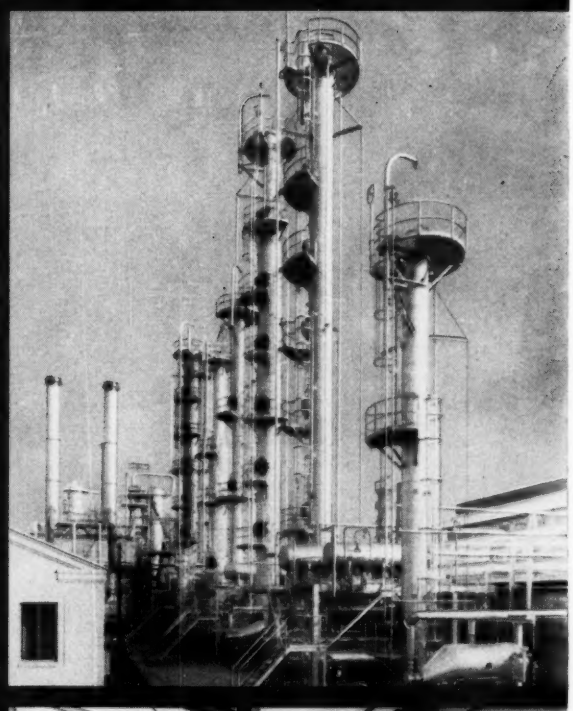
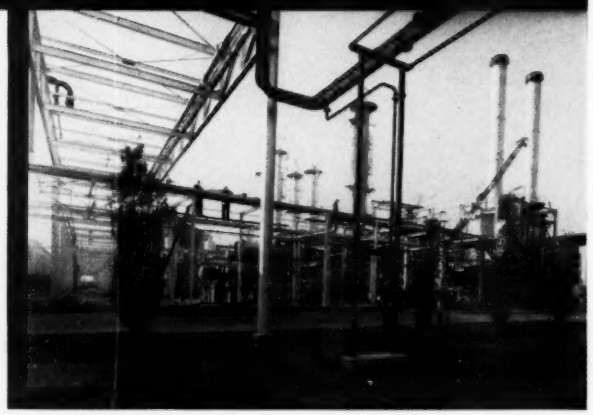
In Germany...

ANOTHER JOB WELL DONE BY PROCON



Heat exchanger in foreground, fractionation tower at left and heater stacks on right during construction.





Top—Fractionation section of the finished Platforming and Unifining units.

Bottom—Nearing completion, heat exchangers, left, in series with the fractionation section and heaters on the right.

Procon construction helps rebuild Deutsche Erdöl A.G. refinery at Heide, Germany

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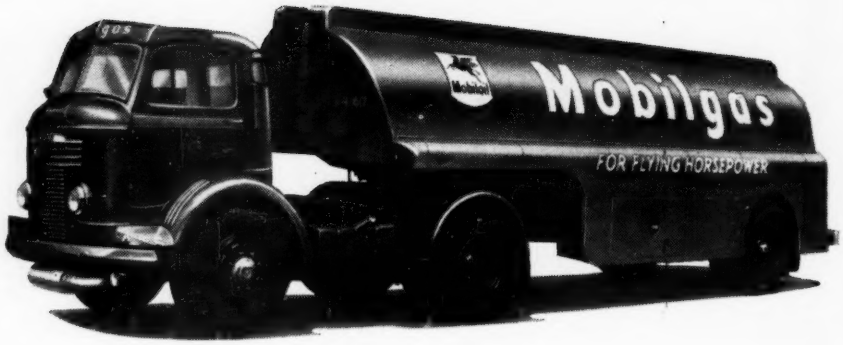

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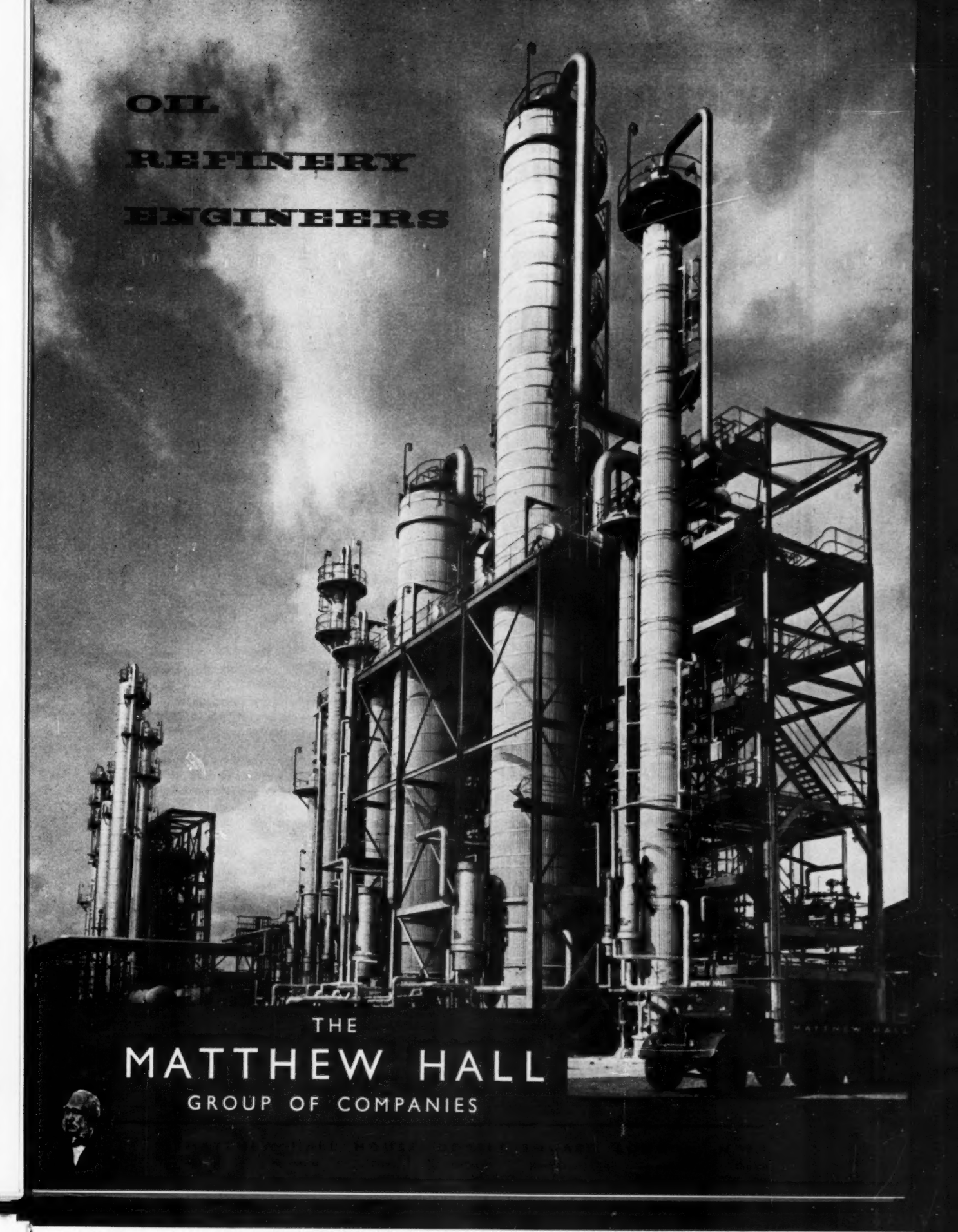
Illustrated:
Above: 2,400 gallon Articulated Mild Steel Petrol Tank on Commer Chassis
Right: A 2,400 gallon 5-Compartment tank mounted on Bedford Tractor and Carrimore running gear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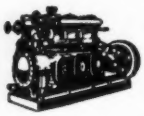

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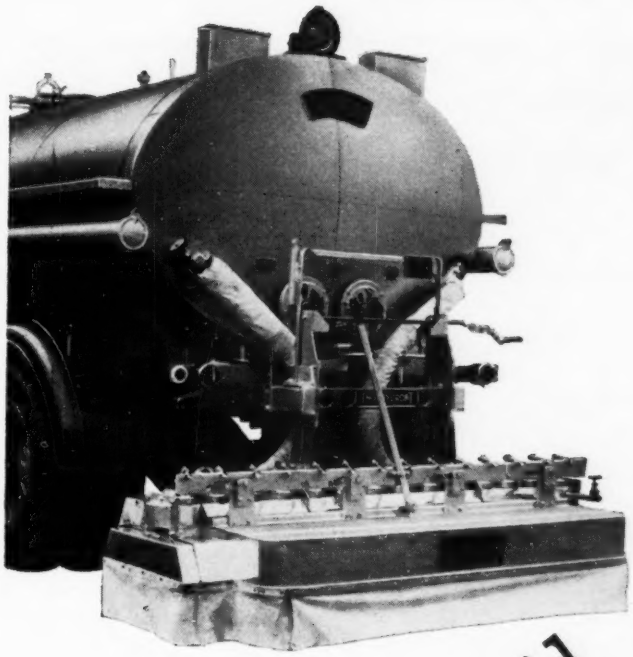
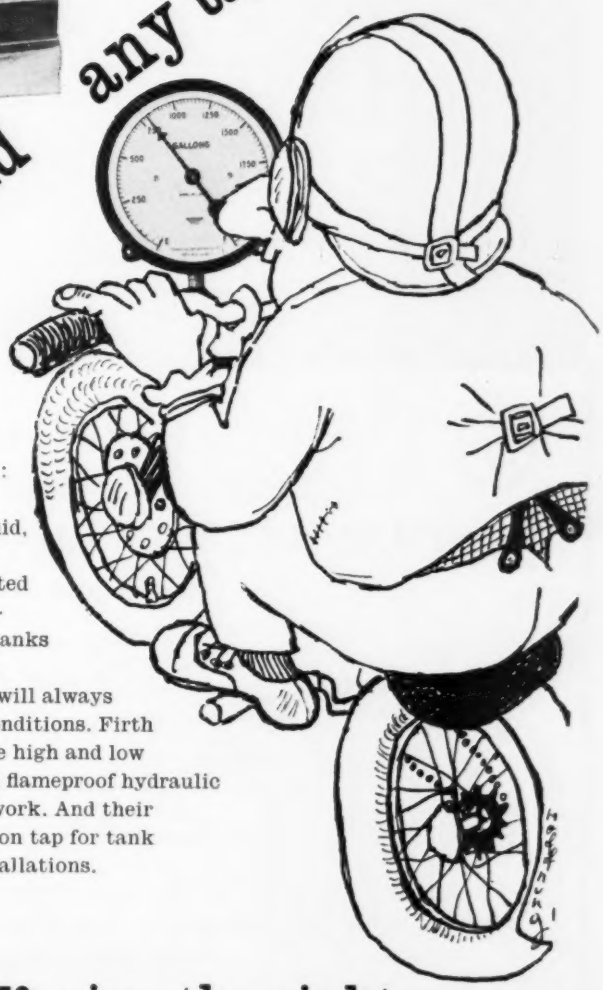


any liquid any tank anywhere



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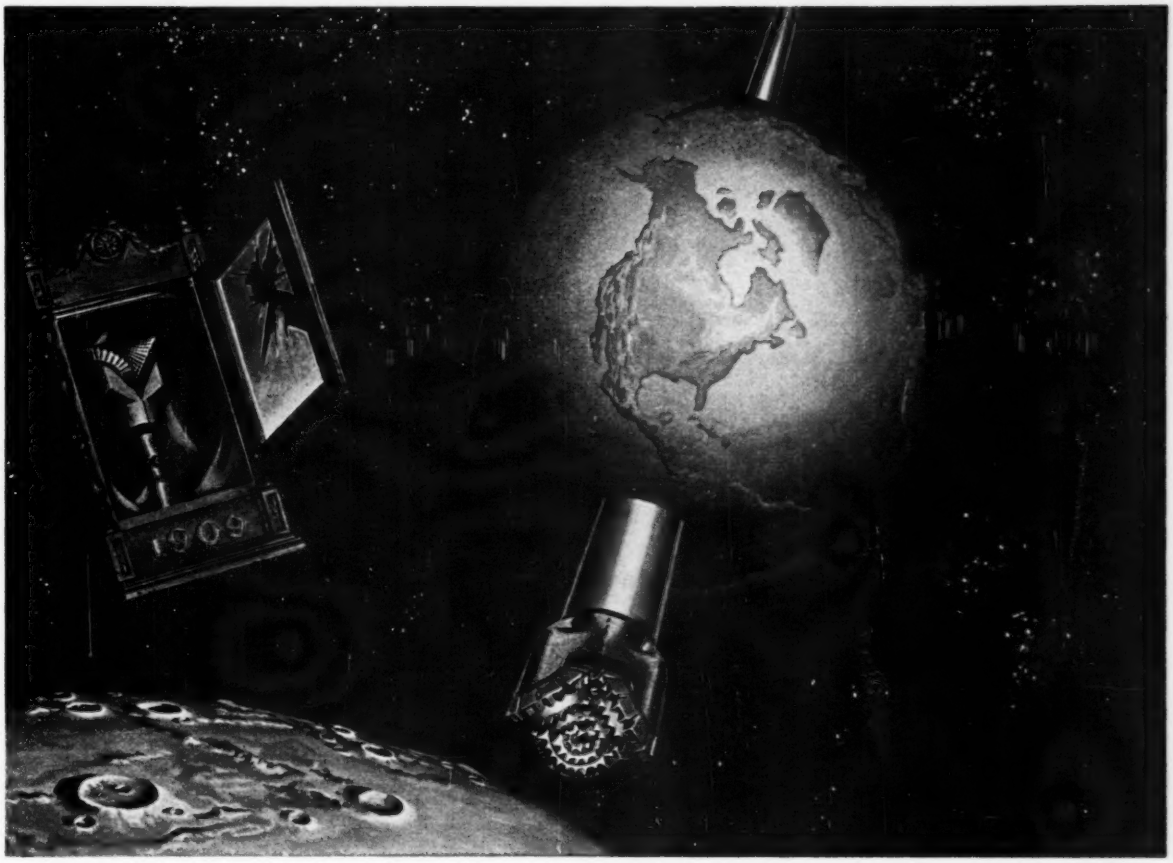

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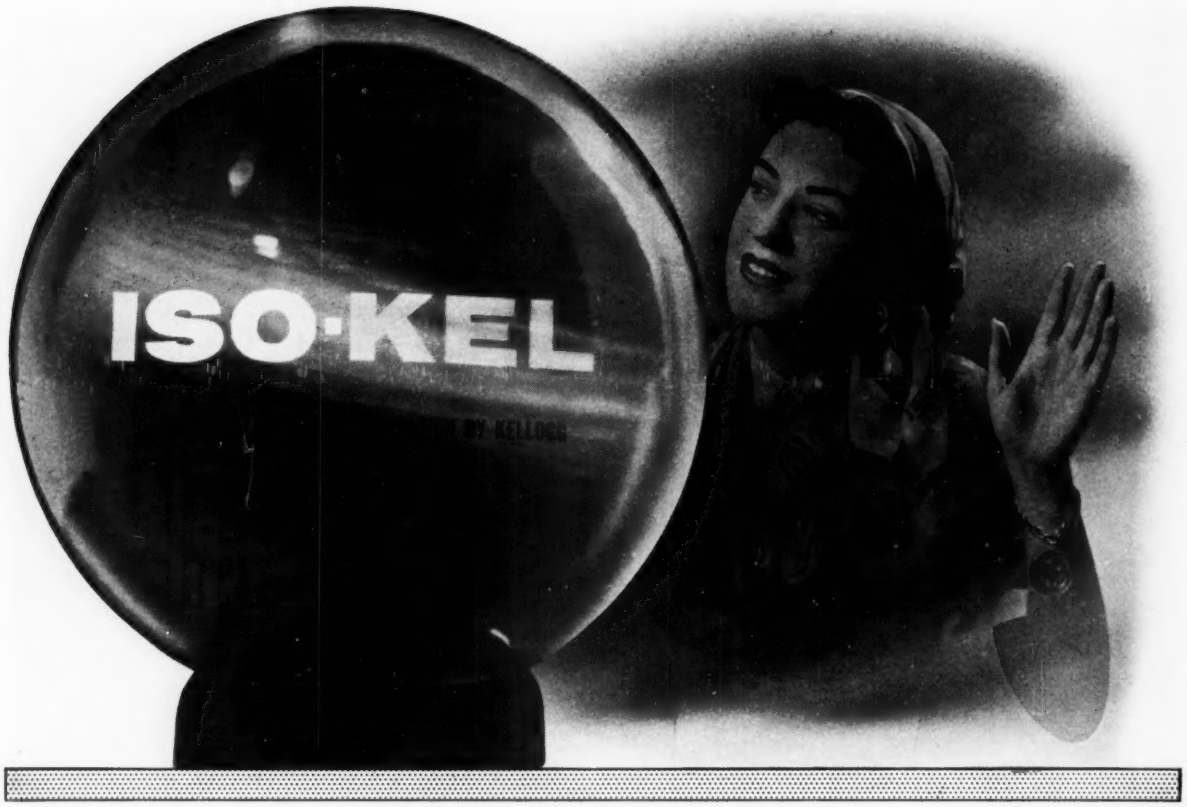

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